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THE GOLDSBORO RIDGE, AN ENIGMA[1/]

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ABSTRACT

The Goldsboro ridge is a sand body 25 feet high that rises above the Sunderland surface near Goldsboro, North Carolina. It consists of unfossiliferous sands with a few intercalated clay beds. The ridge is neither an erosional outlier nor an eolian feature. It is a depositional ridge, probably of marine origin. The geography of the relationships among the height and orientation of the ridge, the elevation of the toe of the nearby Kenly scarp, the placement of a distinctive slate knoll immediately northwest of the ridge, and the position and orientation of the Neuse and Little Rivers are all compatible with a marine origin. The Goldsboro ridge and the Kenly scarp are the major evidences of a former post-Miocene sea stand above 95 feet (Surry scarp).

INTRODUCTION

The Sunderland surface near Goldsboro, North Carolina, is a flat and uninteresting plain with an altitude of about 110 to 120 feet. East of Goldsboro along U. S. Highway 13, this plain is broken by a sandy ridge rising to an altitude of 140-145 feet for a length of 5 miles.

1/ Paper number 3146 of the Journal Series. Joint contribution from the Soil Conservation Service, U. S. D. A., and the Department of Soil Science, North Carolina Agricultural Experiment Station, Raleigh, North Carolina.

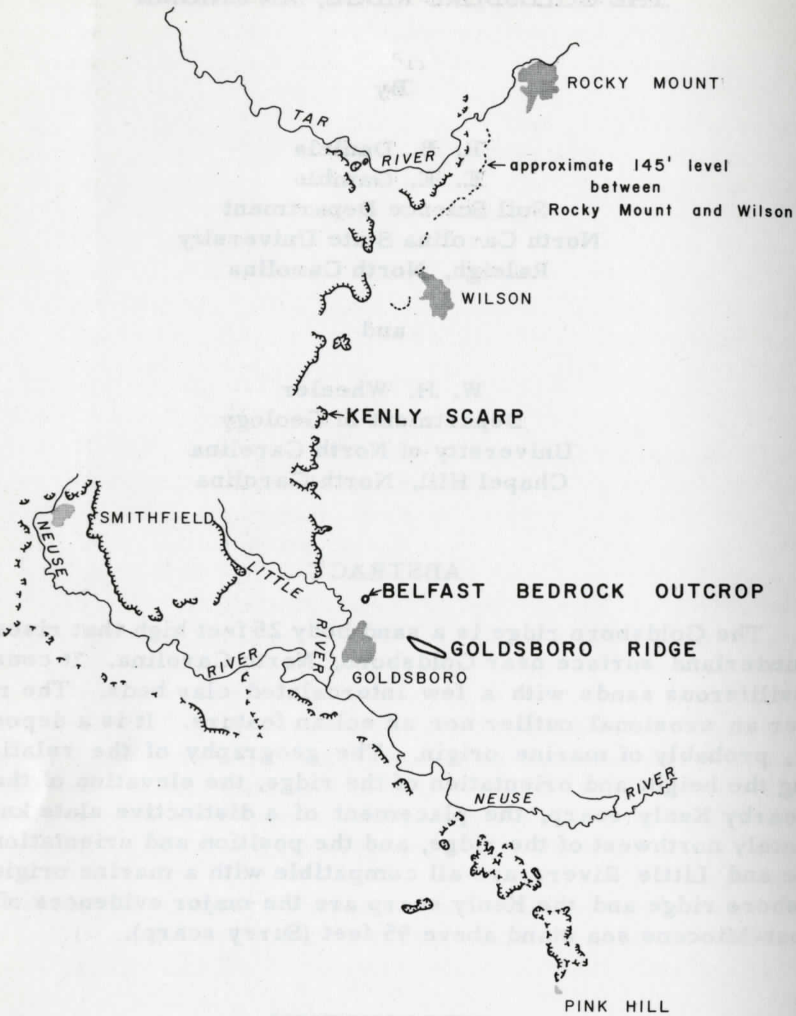

Figure 1. Location of Goldsboro ridge in relation to scarps and the Neuse River valley. The line is at the toe of the scarp and the ticks point to the higher elevations.

This ridge, which we call the Goldsboro ridge, is oriented northwest-southeast and is only 3/4 mile wide. The ridge is between West Bear Creek and Walnut Creek and is completely surrounded by nearly level topography with a relief of about 5 feet. It is slightly asymmetric and is steeper on the southwest side. It has a gently undulating crest and two distinct Carolina bays at the southeast end.

The ridge is five miles east of the Kenly scarp and is oriented perpendicular to it. The ridge lies about 14 miles southeast of the prominent line of rock outcrop associated with the Kenly scarp south of Bailey. The long axis of the ridge points northwest toward the slate knoll at Belfast. This knoll is the easternmost inlier of slate in this portion of the Coastal Plain.

Previous workers did not recognize the Goldsboro ridge, apparently because it did not show on the topographic maps available to them. The ridge probably does not warrant more than casual interest when considered alone. But when the characteristics of the ridge are considered in relation to scarps, terrace surfaces, and the Neuse River valley, many new alternatives for the genesis of this segment of the middle Coastal Plain can be seen.

STRATIGRAPHY

The stratigraphy of the area is shown in Figure 2. The Black Creek Formation was not reached in most of our bore holes because it is buried by 10 to 20 feet or more of the Yorktown Formation. The dark colored laminated sands and clays of the Black Creek Formation are distinctive and easily recognized. The contact between it and the overlying Yorktown is abrupt. We identified the Yorktown Formation in every bore hole that penetrated the surficial sediments. The upper 5 to 10 feet of the formation was unfossiliferous, and fossils were encountered in only one deep bore hole. The contact between the Yorktown and the surficials is abrupt and easily recognized because the sticky greenish-gray silty Yorktown contrasts with the nonsticky gray coarse sandy surficials. In less than 10 percent of our bore holes the Yorktown at this contact with the surficials had weathered to a brownish yellow smooth clay.

The surficial sediments under the plain near Goldsboro have been called the Sunderland Formation by Stephenson (1912) and Post-Miocene deposits undifferentiated by Pusey (1960). At this time, we are not sure whether the Sunderland Formation of Stephenson is a separate entity, or whether Pusey was more nearly correct. For these reasons we will use the term Sunderland Formation for the sediments underlying the Sunderland geomorphic surface. The informal name Goldsboro sand will be used for the sediments of the Goldsboro ridge and the equally high knoll at Cokers Crossroads.

The Sunderland Formation has an upper fine and lower coarse component. The lower one-half of the formation near Goldsboro is coarse textured and has conspicuous cross-bedding and repeated channeling. Gravel layers and clay-ball conglomerates are common at the bottoms of channels. We interpret these features as evidence for a fluvial origin for the basal part of the Sunderland. These features are well shown in a road cut along Wayne County road 1556 about 0.4 mile northeast of its junction with Bypass U. S. 70. The base of the forma-

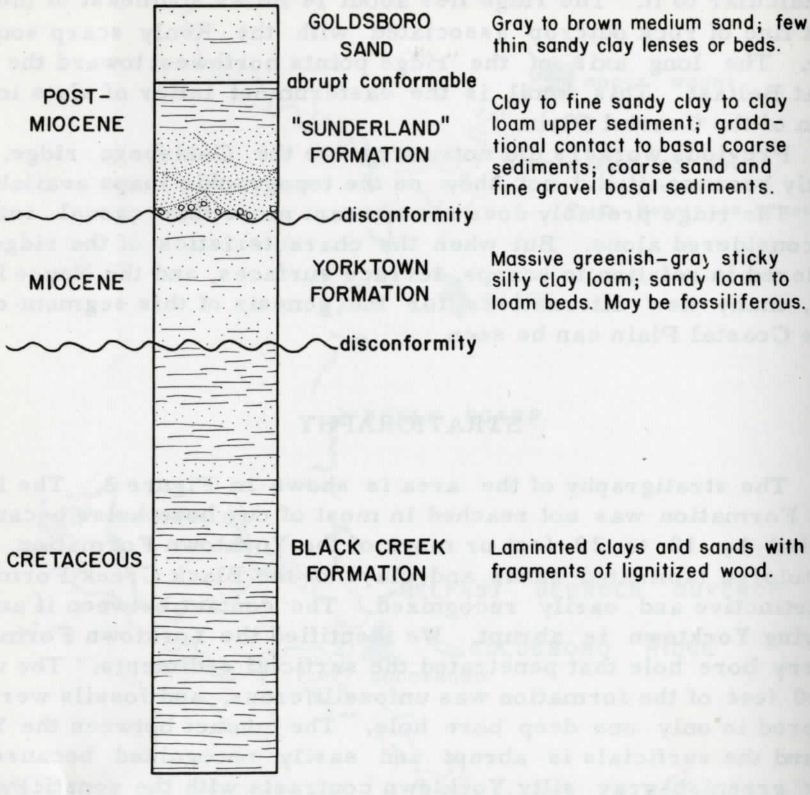

Figure 2. Stratigraphy in the vicinity of the Goldsboro ridge.

tion is gently undulating and slopes to the southeast. The contact with the Yorktown is best seen on Wayne County road 1565 about 200 feet north of its junction with 1588.

The lower half of the Sunderland Formation is dominantly a coarse to medium sand to sandy loam. A basal coarse gravelly sand has pebbles up to 2 cm. in diameter. The coarse lower half grades upward into a finer grained sandy clay loam to clay that is massive with little indication of bedding. The sands become finer as the silt content increases.

Localized clay beds occur in the upper 10 feet of the formation. One 11-foot thick bed of nearly pure clay was found under the northwest edge of the ridge. This bed grades laterally to the west, east and north for several miles with an increase in silt. These clay or clayey beds are found at or near the top of the formation and no fossils have been found in them or anywhere else in the Sunderland.

The Goldsboro sand is present in the Goldsboro ridge and in a low subcircular knoll about 2 1/2 miles in diameter lying about 4 miles northeast of the Goldsboro ridge around the hamlet of Cokers Cross-

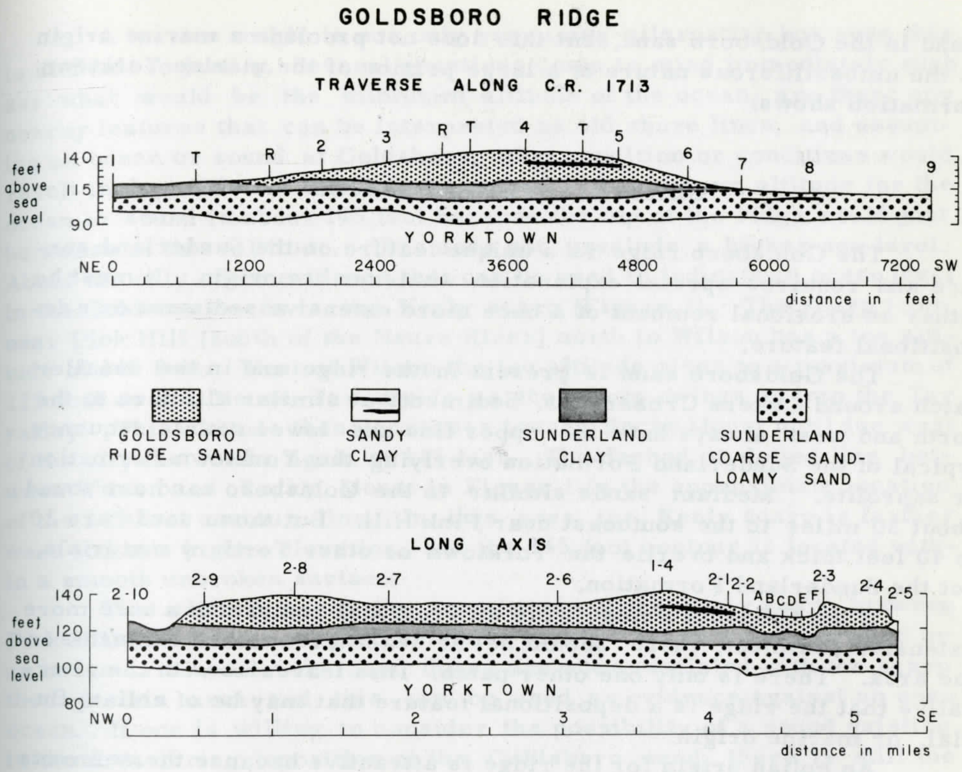

Figure 3. Cross sections of the Goldsboro ridge. Numerals 1 to 9 and 2-1 to 2-10 are bore hole locations along traverse 1, county road 1713, and traverse 2, the long axis. Letters A to F locate closely spaced bore holes in the Carolina Bay. Letters R and T along road 1713 are resistivity and topographic points used in constructing the cross section.

roads. It is dominantly a loamy sand to sandy loam composed of medium sands and a few intercalated clay layers (Figure 3). The sand diameters in the Goldsboro sand are about the same as those in the upper half of the Sunderland but they have less clay. The clay content of the Goldsboro sand is about the same as the basal coarse Sunderland. The Goldsboro sand overlies the Sunderland Formation conformably. The contact is always abrupt but there is no evidence of deep channeling, basal coarse material, and evidence of weathering at the contact. Even the Carolina Bays do not disturb the underlying Sunderland materials (Figure 3). The sand in the bay rim is not different from the Goldsboro sand. Therefore, these Carolina Bays are merely surface features associated with the formation of the ridge. The contact between the Goldsboro sand and the Sunderland is easily recognized by the abrupt decrease in clay content and the large increase in silt. No fossils were found in the Goldsboro sand, but this does not preclude a marine origin as the unfossiliferous nature of a large portion of the marine Yorktown Formation shows.

GENETIC INTERPRETATION

The Goldsboro ridge is a unique feature on the Sunderland surface and requires special explanation whatever its origin. It must be either an erosional remnant of a once more extensive sediment or a depositional feature.

The Goldsboro sand is present in the ridge and in the smaller patch around Cokers Crossroads. Sediments at similar altitudes to the north and west always have the upper fine and lower coarse sequence typical of the Sunderland Formation overlying the Yorktown Formation or saprolite. Medium sands similar to the Goldsboro sand are found about 30 miles to the southeast near Pink Hill. But those sands are 20 to 40 feet thick and overlie the Yorktown or other Tertiary materials, not the Sunderland Formation.

If the Goldsboro ridge were an erosional remnant of a once more extensive sediment, there should be at least a few other remnants in the area. There is only one other patch. This leaves us with the alternative that the ridge is a depositional feature that may be of eolian, fluvial, or marine origin.

An eolian origin for the ridge is attractive because the sediments to the south and southwest are sandy and could be a source area. But the sediments to the west and north are silty and could not provide sufficient sand. The lack of outcrops prevented us from examining the sedimentary structures of the Goldsboro sand, so this clue to its depositional history is not available. One six foot section near the base was sampled by driving a plastic tube into the sand. The bedding was all horizontal. The intercalated clay beds and the absence of dune topography argue against an eolian origin for the ridge.

If the ridge was deposited by water, we have two alternatives, fluvial or marine. There is little in the Goldsboro sand that argues against a fluvial origin except its very uniform grains size. There is no coarse basal sediment, and except for the clay lenses the sand is monotonously similar from top to bottom. This, however, is not enough to reject a fluvial origin. The limited distribution of the Goldsboro sand indicates that if it is fluvial it must be similar to a natural levee. But there is no companion levee, and no paralleling river channel. Possibly traces of these features have been destroyed, but by what mechanism? The Goldsboro sand is post-Sunderland surface. How could a post-Sunderland surface river channel and matching levee be destroyed so the Sunderland surface is reconstructed without a trace of its being disturbed? Thus, we must consider an alternative to the fluvial origin for the ridge.

A marine origin is our only remaining alternative but even this is difficult to justify. Several questions come to mind immediately such as: what would be the minimum altitude of the ocean, are there any nearby features that can be interpreted as old shore lines, and assuming an ocean or sound at Goldsboro, what condition or conditions would result in deposition of the Goldsboro sand? A minimum altitude for the ocean or sound is about 145 feet because the top of the ridge would just be awash at this altitude. This does not preclude a higher sea level. About the only other evidence that can be used to indicate an ocean level in the Goldsboro area is the Kenly scarp (Figure 1). The scarp from near Pink Hill (south of the Neuse River) north to Wilson has a toe altitude of 145 feet. West of Wilson the toe altitude rises to a maximum of 175 feet on the Neuse-Tar divide as the scarp swings up into the Tar valley. This altitude then decreases toward Rocky Mount until due west of the city the toe is again at 145 feet. The dashed or dotted line between Wilson and Rocky Mount in Figure 1 is the approximate location of the 145 foot contour line. In this area the Kenly scarp is farther west and at a higher elevation, and the 145 foot contour is located within a smooth unbroken surface.

The uniformity of the toe altitude of the Kenly scarp between Pink Hill and Wilson is good evidence that the scarp was controlled by an ocean or sound level. Sand dunes are not associated with the scarp through this area and this can be used as evidence against an open ocean. If one is willing to consider the possibility of a sound existing in the area during deposition of the Goldsboro sand, there is still the question of what conditions existed at this site. The ridge is roughly aligned with the flow direction of the Neuse, and is southeast of and aligned with a slate knoll near Belfast[2/], and is aligned with the southeast trending segment of Little River (Figure 1). The Goldsboro ridge is near the junction of possible north-south longshore currents generated by the Neuse and Little Rivers in an estuary. With sea level at 145 feet the water depths between the slate knoll and the Kenly scarp would be 10 feet or less, but they would be 25 to 30 feet at the base of the Goldsboro ridge. The shallow depths, the slate knoll, and currents from the Neuse and Little Rivers could deflect long shore currents, turning them perpendicular to the shore. The sand could be supplied by the longshore currents of the Neuse and Little Rivers, or both. The result was a shoal area built by the interaction of southerly drift along the coast and the eastward flowing current generated by the Neuse and Little Rivers. The largest feature by far of this shoaling and sedimentation is the elongate Goldsboro ridge. An argument supporting this

2/ The slate knoll is a sharp conical hill of Carolina Slate rising to 150 feet. It is about 3 miles north of the junction of U. S. 70 and U. S. 117 in Goldsboro. The slates are well exposed in a cut of the Seaboard Coast Line Railroad.

mode of deposition is the asymmetry of the ridge. It is steeper on the south side than the north. This suggests that currents on the river side may have been strong enough to erode the ridge after the main period of deposition. The uniform grain size of the "Goldsboro sand" also is not contrary to deposition in a sound.

A marine origin for the Goldsboro ridge can be opposed on several grounds. The absence of marine fossils is the most valid objection. The uniqueness of the ridge may be said to make it difficult to prove a marine origin, but this quality would oppose any origin with equal weight. The reasons for choosing marine conditions over others as the probable origin lie in the geography of the relations among the height and orientation of the ridge, the elevation of the toe of the nearby Kenly scarp, the location of the Belfast slate knoll, and the positions and orientation of the ridge, the elevation of the toe of the nearby Kenly scarp, and the positions and orientation of the Neuse and Little Rivers. All these suggest a marine origin.

But, until much more is known about all the middle Coastal Plain, the Goldsboro ridge will remain, in the last analysis, an enigma.

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CHEMISTRY AND MINERALOGY OF METASEDIMENTARY ROCKS IN THE ALBEMARLE AREA, NORTH CAROLINA

SLATE BELT

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ABSTRACT

Metasedimentary rocks in the Albemarle area, North Carolina slate belt, are mainly argillites, tuffaceous argillites, and graywackes. The rocks are interlayered with and gradational into metavolcanic rocks described in an earlier report (Butler and Ragland, 1969). Samples from eight localities, including type localities of the Tillery Formation, McManus Formation, and Yadkin Graywacke (Conley and Bain, 1965), were selected for bulk chemical and X-ray modal analysis. The rocks are composed mainly of quartz, albite, muscovite, and chlorite, with smaller sporadic amounts of biotite, actinolite, epidote, calcite, microcline, and opaque minerals. Mineral assemblages are indicative of lower greenschist facies (biotite or chlorite zone) of regional metamorphism. The rocks have been affected by metasomatism, but retain bulk chemical compositions generally similar to argillite and graywacke from other regions.

INTRODUCTION

The Albemarle area of the Carolina slate belt in North Carolina includes a thick section of mildly deformed meta-igneous and metasedimentary rocks of Early Paleozoic and possibly Late Precambrian age. The rocks have been regionally metamorphosed to assemblages of the lower greenschist facies. The relatively good outcrops, varied lithology, and preservation of many original features of the rocks have attracted a number of geologists; consequently the area is one of the most intensively studied regions in the crystalline Southern Appalachians. An earlier study (Butler and Ragland, 1969) concentrated on the meta-igneous rocks of the region. In this paper, we present chemical and modal data for the dominantly metasedimentary formations described by Conley and Bain (1965), including samples from three type localities and five other selected exposures.

Acknowledgments

Paul C. Ragland assisted at several stages of the investigation. Kent C. Nielsen helped with the X-ray analysis. Daniel A. Textoris suggested improvements in the manuscript. Financial assistance was mainly from a grant to Butler by the Research Council of the University of North Carolina at Chapel Hill. The atomic absorption spectrophotometer and X-ray spectrograph were purchased with grant funds from the North Carolina Board of Science and Technology.

GENERAL GEOLOGY

Detailed mapping in the Albemarle (Conley, 1962) and Denton (Stromquist, 1966) quadrangles in the Carolina slate belt (Figure 1) stimulated a series of studies in the region (Butler and Ragland, 1969; Randazzo, 1968, 1969; Weigand, 1969; Upchurch, 1968; Burt, 1967) and helped provide the basis for regional syntheses (Conley and Bain, 1965; Stromquist and Sundelius, 1969). Figure 2 gives the stratigraphic nomenclature used in the region and the thickness of major units. The rocks are derived mainly from volcaniclastic deposits, lava flows, and associated clastic sediments. Most units were probably deposited in a submarine environment, but some have evidence for subaerial deposition. Sources of volcanic and sedimentary materials were mainly within the region, and several possible vent areas have been identified (Stromquist and Conley, 1959; Conley, 1962; Stromquist and Sundelius, 1969). Volcanic rocks range in composition from rhyolitic to basaltic (Butler and Ragland, 1969). As might be expected in a deformed volcanic sequence that includes some of the vent areas, stratigraphic relationships are confusing in many places. There is controversy over the existence of an unconformity between the Albemarle and Tater Top Groups and the status of units placed in the Tater Top Group (Conley, 1962; Conley and Bain, 1965; Stromquist and Sundelius, 1969).

METHODS

Chemical analyses were made by rapid methods generally similar to those described by Butler and Ragland (1969, p. 704-706). The following methods were used for the oxides given: (1) Atomic absorption spectrophotometry - Al_2O_3, K_2O, MgO, MnO, Fe_2O_3, CaO, K_2O; (2) X-ray fluorescence - SiO_2; and (3) Colorimetry - FeO, TiO_2. X-ray modes were used to calculate H_2O^+.

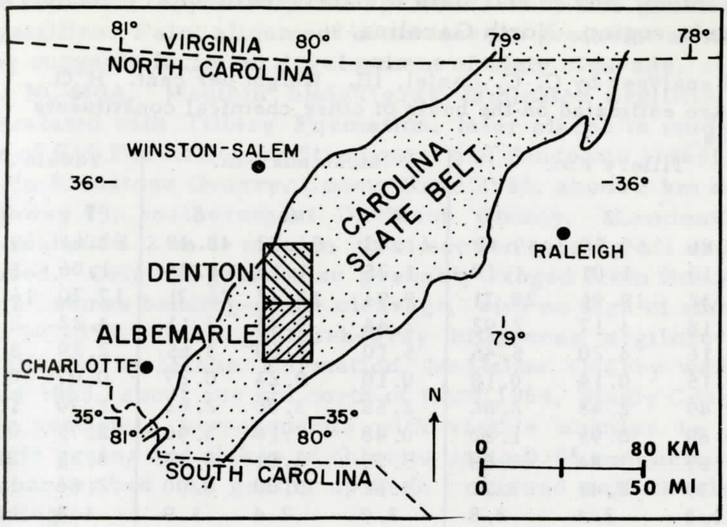

Figure 1. Index map of the Carolina slate belt in North Carolina, showing location of the Albemarle and Denton quadrangles.

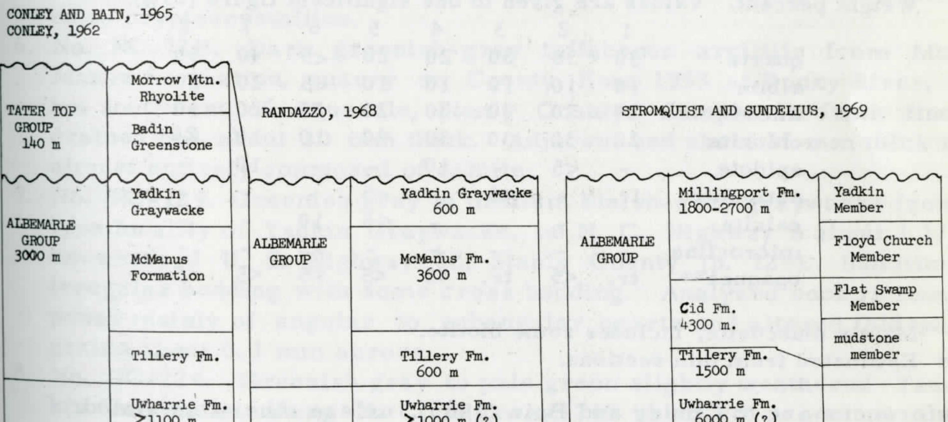

Figure 2. Stratigraphic nomenclature and approximate thickness of units, southwestern part of the Carolina slate belt, North Carolina.

Samples were studied by microscopic and X-ray diffraction procedures. X-ray modal analyses (Table 1) were determined from diffraction patterns of whole-rock powders with random orientation, using a method modifier after Tatlock (1966). The method is described in more detail by Butler and Ragland (1969) and was also used by Randazzo (1968, 1969) and Weigand (1969).

Table 1. Chemical and modal data for metasedimentary rocks, Albemarle region, North Carolina.

A. Chemical analyses by C. C. Daniel, III. Weight per çent. H_2O and CO_2 are estimated on the basis of other chemical constituents and modes.

	Tillery Fm.			McManus Fm.			Yadkin Fm.	
	1	2	3	4	5	6	7	8
SiO_2	57.86	59.50	59.82	61.43	56.72	48.48	62.61	69.03
TiO_2	1.19	1.01	1.10	1.25	1.19	1.84	1.06	1.16
Al_2O_3	21.32	19.06	20.71	19.94	18.42	26.71	17.20	16.32
Fe_2O_3	5.18	4.17	2.92	2.44	3.46	3.11	4.22	2.35
FeO	4.16	4.20	5.46	5.10	6.69	3.65	2.29	3.45
MnO	0.15	0.14	0.18	0.10	0.24	0.27	0.07	0.09
MgO	2.49	2.48	2.86	2.56	3.06	2.62	1.70	1.35
CaO	0.69	0.95	1.22	0.48	1.10	3.90	2.75	0.45
Na_2O	1.59	3.84	2.88	3.29	3.01	0.94	3.35	2.72
K_2O	3.35	2.45	3.25	3.62	3.60	8.00	2.86	1.55
H_2O+	2.3	2.4	2.8	2.9	2.4	1.9	1.4	1.5
Total	100.28	100.20	103.20	103.11	99.89	104.12*	99.51	99.97

*Includes 2.7% CO_2

B. Semi-quantitative X-ray modal analyses by J. R. Butler and K. C. Neilsen. Weight percent. Values are given to one significant figure (±5%).

	1	2	3	4	5	6	7	8
quartz	30	30	30	20	20	<5	40	50
albite	10	10	10	10	10	<5	20	20
mica*	30	20	30	30	20	70	20	10
chlorite	20	30	30	30	30	10	10	20
epidote	-	<5	-	10	-	-	10	-
actinolite	tr.	-	<5	-	<5	-	-	-
calcite	-	-	-	-	<5	10	-	-
microcline	-	-	-	-	-	<5	-	-
opaques**	tr.	<5	tr.	<5	<5	<5	<5	<5

* Mainly muscovite, includes some biotite.
** Estimated from thin sections.

References are to Conley and Bain (1965), unless otherwise stated.

1. No. NC-218A. Laminated argillite from type locality of Tillery Formation, just south of Uwharrie River on N. C. Highway 109, Montgomery County (p. 127). Evenly laminated greenish-gray to dark greenish gray rock with beds ranging from less than 1 to 6 mm thick. Very fine grained to cryptocrystalline. Well-developed graded bedding in thin section. Good cleavage approximately perpendicular to bedding is seen in both hand specimen and thin section.
2. No. NC-11. Light olive-gray laminated argillite from Tillery Formation, hill west of Lake Tillery on N. C. Highway 27, Stanly County. Laminations are 1 to 8 mm thick; some are distinctly graded

and some are apparently homogeneous. Very fine grained to cryptocrystalline. Faint alignment of micaceous grains at an angle to bedding suggests incipient development of slaty cleavage.

3. No. NC-40A. Medium bluish-gray laminated argillite, originally correlated with Tillery Formation, later placed in mudstone member of Cid Formation by Stromquist and Sundelius (1969); from Nor-Carla Bluestone Quarry, County Road 2545, about 2 km south of N. C. Highway 49, southernmost Davidson County. Laminations range from about 1.2 to 4 mm in thin section; nearly all are beautifully graded. Original grain size probably ranged from fine silt to clay. Rock shows bedding-plane cleavage, with no sign of slaty cleavage.
4. No. NC-138. Dark greenish-gray tuffaceous argillite from type locality of McManus Formation, McManus Quarry west of County Road 1963, about one km north of Road 1964, Stanly County (p. 127). Thin section is homogeneous with visible angular to subrounded quartz grains and flakes of chlorite up to 0.05 mm across. Section of coarser bed has grains up to 0.1 mm and well-developed graded bedding.
5. No. NC-136. Dark greenish-gray tuffaceous argillite from reference locality of McManus Formation, on N. C. Highway 27 By-pass just east of U. S. Highway 52, southern edge of Albemarle, Stanly County (p. 127). Beds are massive to faintly graded and range in thickness from 2 mm to 50 cm. Analyzed rock is very fine grained to cryptocrystalline.
6. No. NC-72B. Dark greenish-gray tuffaceous argillite from McManus Formation, quarry on County Road 1953 at Rocky River, 4 km southwest of Aquadale, Stanly County. Sample is from fine-grained bed about 30 mm thick. Adjacent bed about 35 mm thick is almost entirely composed of calcite.
7. No. NC-129. Greenish gray to medium bluish-gray graywacke from type locality of Yadkin Graywacke, on N. C. Highway 8 about 1 1/2 km north of U. S. Highway 52, Stanly County (p. 129). Indistinct irregular bedding with some cross bedding. Analyzed rock is composed mainly of angular to subangular quartz and altered feldspar grains about 0.1 mm across.
8. No. NC-224. Greenish gray to pale green slightly weathered Yadkin Graywacke, along N. C. Highway 740 about 70 m northwest of County Road 1571, near Badin, Stanly County. Analyzed sample is homogeneous with no obvious bedding. Relict texture indicates original grains were mostly angular to subangular with average diameter of about 0.1 mm. Plagioclase, quartz, chlorite, and muscovite can be identified in thin section.

METASEDIMENTARY ROCKS IN THE ALBEMARLE AREA

The samples selected for analysis (Table 1) are from the type localities of the Tillery Formation, McManus Formation, and Yadkin Graywacke, plus five additional samples from reference localities and a particularly interesting quarry. Since the localities are from the formations named by Conley and Bain (1965), we use their nomenclature in this report. Stromquist and Sundelius (1969) have suggested redefinition and re-interpretation of some of the units.

The most characteristic rock of the Tillery Formation is a laminated argillite with very regular beds generally less than 2 cm thick. The McManus Formation is generally thicker bedded and sandy units are common. The Yadkin Graywacke is composed mainly of sand-size material, bedding may be more than one m thick, and cross bedding as well as graded bedding is common. The inferred pre-metamorphic nature of the rock fits the definition of graywacke given by Krumbein and Sloss (1963, p. 172). Full descriptions of rock units have been given in previous reports.

All of the map units in the area are very heterogeneous and there are all possible gradations and mixtures between pyroclastic and sedimentary rocks. The samples described here were chosen to be most representative of rocks of probably sedimentary origin that are widely distributed through the stratigraphic section.

The major minerals are quartz, mica, chlorite, and albite, with some sporadic occurrence of epidote, actinolite, carbonate, and microcline. A small percentage of opaque minerals is ubiquitous. The opaque minerals probably include pyrite, hematite, magnetite, and graphite, but no quantitative information was obtained. Weigand (1969, p. 27) detected graphite in five samples of tuffaceous argillite. The carbonate mineral effervesces vigorously with dilute hydrochloric acid and the d-spacing of the (211) peak is approximately the same as for pure calcite, so it is here identified as calcite. Biotite is difficult to distinguish from muscovite on whole-rock diffractograms (Butler and Ragland, 1969; Randazzo, 1969, p. 82). The values for mica in Table 1 probably represent mainly muscovite with minor amounts of biotite. Biotite is common in the Albemarle area, but was rarely seen in thin sections studied for this report; however, many of the rocks are too fine-grained for microscopic identification of minerals.

There are few consistent differences between analyses for argillite (Tillery Formation) and for tuffaceous argillite (McManus Formation), consequently the six analyses will be discussed together. The most striking variations between the analyses are for SiO_2, CaO, Na_2O, and K_2O. These variations may represent original differences or later metasomatism. Weigand (1969) cited evidence for metasomatism in the Albemarle area that was probably controlled by the pressure gradient across large folds. He postulated that Si, Na, K, and Rb were mobilized and redistributed. In five of the six analyses, K_2O is greater than Na_2O. In contrast, K_2O is less than Na_2O in 51 of 58 analyses of meta-igneous rocks in the Albemarle area (Butler and Ragland, 1969, Table 5). Most types of weathering cause an increase in the K_2O/Na_2O ratio (Butler, 1964), which indicates that the argillites may contain partly weathered detritus. Sorting of pyroclastic debris could cause differences in K_2O/Na_2O ratio. For example, biotite flakes could be concentrated in one sediment, plagioclase clasts in another. This possibility is difficult to evaluate because the rocks have been recrystallized.

The graywackes (Table 1) are most similar in composition to andesitic and dacitic tuffs among the meta-igneous rocks of the region. For both analyses in Table 1, Na_2O is greater than K_2O. The graywackes may be mainly reworked pyroclastic debris little affected by weathering.

In Table 2, means for argillite and graywacke analyses are compared with compositions of similar rocks from other regions. Analysis 6 of Table 1 is omitted from the argillite mean, because it is composed almost entirely of mica with a little chlorite and calcite, and is apparently anomalous. The argillite of this report is generally similar to New Zealand argillite (Reed, 1957), which is also from a thick volcanic-sedimentary sequence. The mean for two Yadkin graywackes (Table 2) compares with the mean for 61 graywackes from wide spread regions (Pettijohn, 1963, Table 12) and the mean for 119 Rensselaer graywackes in New York (Ondrick and Griffiths, 1969, Table 2).

The analyses of Table 1 show a relatively high degree of oxidation of iron, when compared to analyses of associated meta-igneous rocks in the Albemarle area (Butler and Ragland, 1969, Table 5). The oxidation may be additional evidence for weathering before deposition of the argillites and graywackes. The means for Albemarle rocks also show stronger oxidation than the means for rocks of other areas (Table 2).

CONCLUSIONS

The laminated argillites resulted from rhythmic sedimentation in a low-energy environment below wave base (Randazzo, 1968). Currents must have been weak and there was little or no disturbance of bedding by burrowing organisms. The tuffaceous argillites probably represent increased sedimentation rates, most likely due to increased volcanic activity (Conley, 1962, p. 12), but there is little evidence for strong current activity. The thick graywacke units show evidence of strong current activity associated with deposition of volcanic debris that is not strongly reworked or weathered.

Some metasomatism took place during metamorphism, but the bulk compositions of rocks are still generally similar to less altered analogs from other areas. The argillites are different from the

Table 2. Comparison of Analyses of Argillite and Graywacke.

	Argillite			Graywacke	
	1	2	3	4	5
SiO_2	59.07	64.2	65.82	66.7	70.59
TiO_2	1.15	0.70	1.11	0.6	0.64
Al_2O_3	19.89	16.3	16.78	13.5	12.59
Fe_2O_3	3.63	0.72	3.28	1.6	4.97*
FeO	5.12	4.1	2.87	3.5	
MnO	0.16	0.06	0.08	0.1	0.077
MgO	2.69	1.9	1.52	2.1	1.51
CaO	0.89	1.4	1.60	2.5	1.61
Na_2O	2.92	2.2	3.03	2.9	2.76
K_2O	3.25	3.7	2.20	2.0	2.19
H_2O+	4.20	3.4	2.30	2.4	ND
Total	102.97		100.59		

*Total iron as Fe_2O_3.

1. Mean of five analyses of argillite and tuffaceous argillite from the Tillery and McManus Formations. Table 1, numbers 1-5.
2. Analysis of composite samples of 17 argillites, Wellington District, New Zealand. Reed, 1957, Table 3, no. 1. Other constituents: P_2O_5-0.14, S-0.24, C-0.44, H_2O^--0.55.
3. Mean of two analyses of graywackes from the Yadkin Formation. Table 1, numbers 7-8.
4. Mean of 61 analyses of graywackes. Pettijohn, 1963, p. 15, Table 12. Other constituents: P_2O_5-0.2, CO_2-1.2, SO_3-0.3, S-0.1, C-0.1, H_2O^--0.7.
5. Mean of 119 analyses of Rensselaer Graywacke samples from the Troy area, New York. Ondrick and Griffiths, 1969, Table 2, number 2. Other constituents: SrO-0.013, BaO-0.045.

associated meta-igneous rocks in ways that can be attributed to weathering. The graywackes show little evidence of weathering, except perhaps for some oxidation.

X-ray modal analyses show that the rocks are all composed of various percentages of low-rank metamorphic minerals. Available data indicate that regional metamorphism in the area discussed here nowhere reached conditions higher than the biotite zone (lower greenschist facies).

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TRANSPORT OF TRACE METALS TO THE ATLANTIC OCEAN BY THREE SOUTHEASTERN RIVERS

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ABSTRACT

Composition of trace metals in solution in estuaries of three Southeastern rivers are similar. Dissolved iron and possibly manganese decrease in concentration going from fresh to saline waters owing to precipitation. The composition of trace metals in suspended sediment from the estuaries of the three rivers differs, suggesting a relationship to the composition of the respective drainage basin.

The total amount of trace metals transported to the Atlantic in both solution and suspension by these rivers appears to be insufficient to supply more than about 100 Km^2 of average Atlantic deep sea sediment. River runoff appears to be inadequate to explain the trace metal accumulation of North Atlantic deep-sea sediments.

INTRODUCTION

In order to understand the chemical exchange between the continents and the ocean, many studies have been made to determine the amount and composition of material which rivers transport to the ocean in solution, bound in suspended particles, or adsorbed on clays and organic matter. The goal of many of these investigations was to establish the flux of trace metals to the ocean from river runoff. When this information is compared to the rate of accumulation of trace metals in marine sediments, mass balance calculations can be made to assess the adequacy of rivers for supplying the necessary amounts of these elements. Rates of supply of trace metals by rivers, however, are usually based on information gained from areas of the rivers upstream from their estuaries. When these rates are compared to the accumulation rates of the same metals in marine sediments, it is sometimes found that rivers apparently supply some trace metals, such as silver, much faster than they can be accommodated in marine sediments (Turekian, 1968). These discrepancies are often explained by assuming that the excess material is deposited more rapidly in estuarine and coastal sediments than in deep-sea sediments. It is reasonable to assume that certain trace metals will be concentrated in estuarine sediments because many elements become more insoluble or are adsorbed by sediments as they are transported from fresh to saline waters. The use of concentration data from upstream areas of rivers for assessing the influence of continental runoff on the trace metal accumulation in the deep ocean may, therefore, be subject to error because of the lack of consideration of processes occurring in the estuarine zone.

In order to give a clearer picture of the transport of trace metals to the deep ocean from rivers, the composition of samples taken from the lower reaches and estuaries of Southeastern rivers was studied. It is felt that analysis of samples in these areas gives a truer description of the chemical exchange between the rivers and the ocean by eliminating some of the ambiquities in interpretation that arise from analysis of samples taken in upstream areas. Some of the uncertainties regarding processes taking place at the freshwater-saltwater boundary are removed by this approach, since changes in concentrations of metals in the rivers are followed as they are transported into the estuarine zone. In this way a comparison of metal concentrations of samples with other data taken across the estuarine zone will establish whether changes in concentration are a function of physical conditions, such as mixing as indicated by chlorinity, or chemical changes such as precipitation as indicated by relationships between metal concentrations and other parameters (see Figure 5).

Three rivers were selected which represent typical Southeastern rivers in regard to drainage basin and flow rate (Figure 1). The rivers selected were the Satilla, Ogeechee and Altamaha (Figures 2, 3 and 4), all of which have their drainage basins in the state of Georgia. The area of these drainage basins is distributed between the Coastal Plain and Piedmont Plateau provinces as indicated in Table 1. Since all the rivers draining the Southeastern United States have drainage basins composed of one or both of these two provinces, it is felt that information gained on the differences in the chemical characteristics of these rivers at their estuaries can, therefore, be used for more general considerations of rivers in this region.

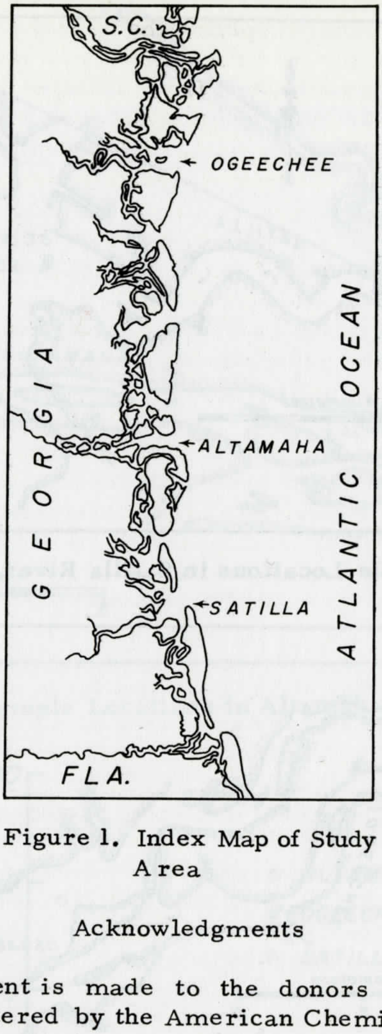

Figure 1. Index Map of Study Area

Acknowledgments

Acknowledgment is made to the donors of the Petroleum Research Fund administered by the American Chemical Society, for partial support of this research.

METHODS

Eh and pH were measured on station using a platinum electrode with Zobell solution as field standard and a standard combination pH electrode, respectively. Approximately three to four liters of water were collected from the surface at each station using plastic samplers. Each sample was filtered through a 0.45 micron millipore filter. All samples were collected in May, 1969.

Chloride was determined in the laboratory by mercuric nitrate titrations in an alchohol medium using diphenylcarbazone and 2-nitroso-1-naphthol as indicator buffer.

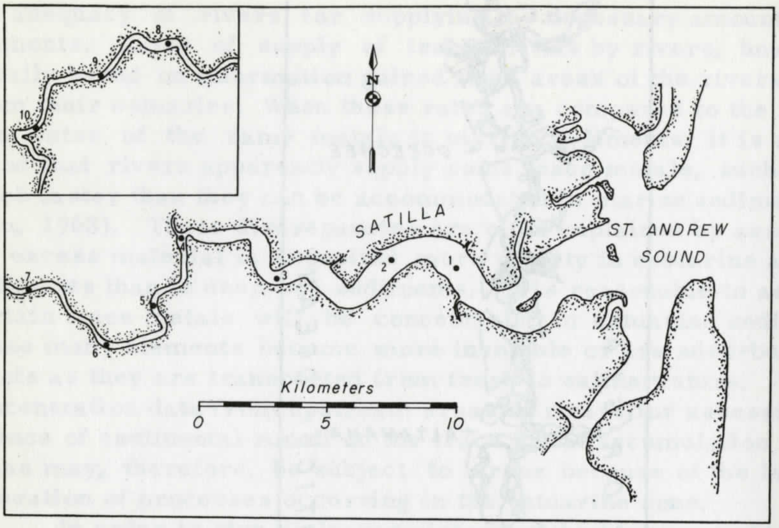

Figure 2. Sample Locations in Satilla River.

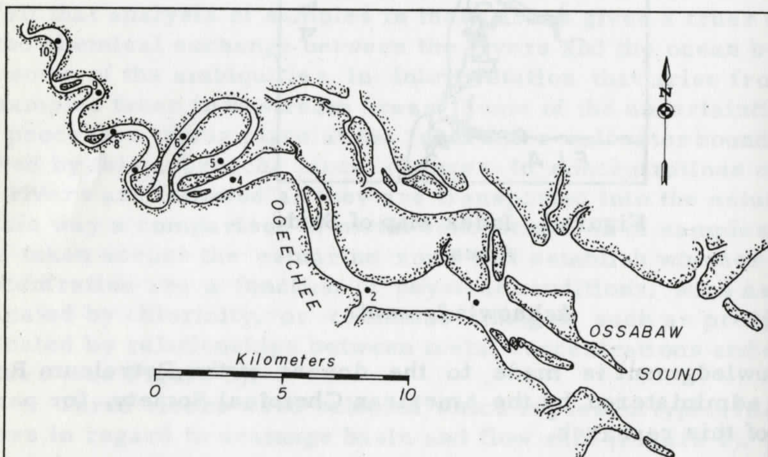

Figure 3. Sample Locations in Ogeechee River.

Metals in solution were concentrated by organic solvent extraction using APDC as the chelating agent and MIBK as the organic phase. This method has been described by Brooks et al. (1967). Concentrated samples were then analyzed by atomic absorption spectrophotometry using a Beckman Model 979 atomic absorption system. Metal concentrations in suspended matter were determined on samples that had been digested using hydrofluoric acid and brought to volume.

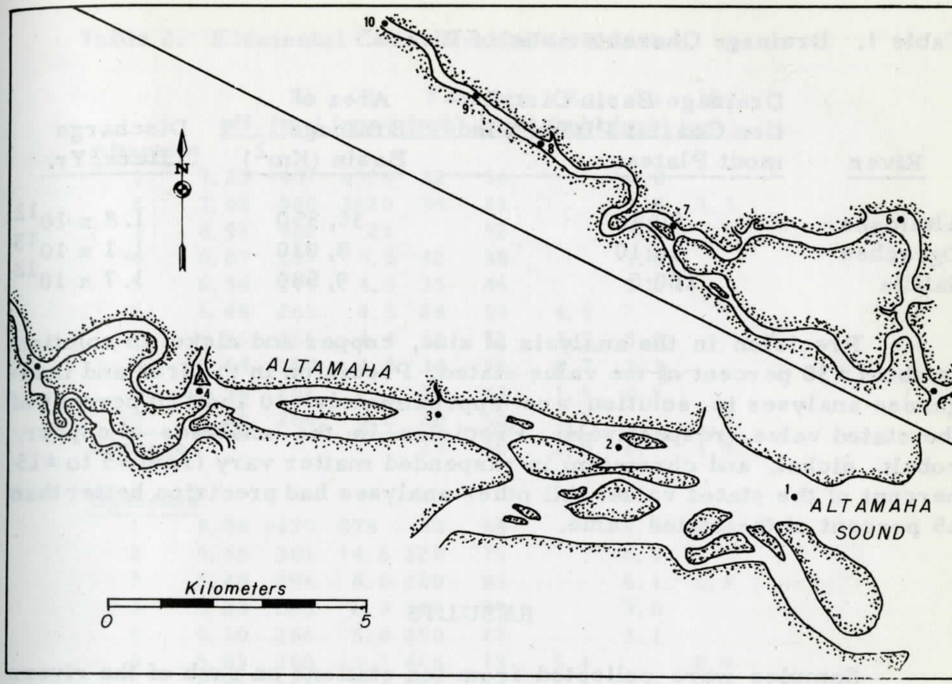

Figure 4. Sample Locations in Altamaha River.

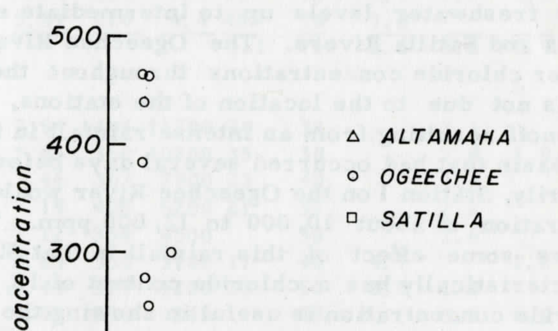

Figure 5. Iron Concentration in Solution (in parts per billion) Versus pH for Southeastern Rivers.

Table 1. Drainage Characteristic of Rivers.

River	Drainage Basin Distribution Coastal Plain: Piedmont Plateau	Area of Drainage Basin (Km^2)	Discharge Liters/Yr.
Altamaha	60:40	35,350	1.8×10^{12}
Ogeechee	90:10	8,030	1.1×10^{13}
Satilla	100:0	9,580	1.7×10^{12}

Precision in the analysis of zinc, copper and nickel in solution is about ±30 percent of the value stated. Precision in the iron and manganese analyses in solution are approximately ±10 and ±20 percent of the stated value, respectively. Precision in the analyses of copper, cobalt, nickel, and chromium in suspended matter vary from ±5 to ±15 percent of the stated value. All other analyses had precision better than ±5 percent of the stated value.

RESULTS

Samples were collected from ten stations on each of the rivers going from the mouth of the river upstream to about 35 to 50 kilometers (Figures 2, 3, 4). As can be seen in Table 2, the chloride values vary from essentially freshwater levels up to intermediate salinity levels for the Altamaha and Satilla Rivers. The Ogeechee River, however, shows much lower chloride concentrations throughout the ten sample stations. This is not due to the location of the stations, but rather to the increased runoff resulting from an intense rainfall in the lower part of the drainage basin that had occurred several days before sample collection. Ordinarily, Station 1 on the Ogeechee River would have a chloride ion concentration of about 10,000 to 12,000 ppm. The Altamaha River also shows some effect of this rainfall in that Station 1 on the Altamaha characteristically has a chloride content of 10,000 to 15,000 ppm. The chloride concentration is useful in showing the mixing of the freshwater runoff with sea water.

Table 2 gives the concentrations of the metals in solution at each station. Analyses for cobalt and chromium were below detectability (less than 1.0 ppb). Blanks in the table indicate that the element was not analyzed in the particular sample for various reasons such as insufficient sample extract. Because analyses for all samples for a given element did not vary greatly in a given river, an average value was obtained which is assumed to represent the amount of that particular element delivered to the ocean by the river. The only case where significant variations occur is in the iron content of the Ogeechee River estuary. Figure 5 shows the iron concentration in solution plotted against pH for all the rivers considered. As indicated in the figure, the

Table 2. **Elemental Concentration in Solution.**

	pH	Eh (mv)	Cl- (ppm)	Fe (ppb)	Mn (ppb)	Zn (ppb)	Cu (ppb)	Ni (ppb)
Altamaha								
1	7.23	+407	6520	32	36		4.0	
2	7.68	380	3620	34	41		1.8	1.5
3	6.92	402	23		52		3.0	
4	6.67	287	5.6	42	38		1.9	
5	6.54	279	4.5	35	46		3.1	
6	6.48	265	4.5	24	53	4.9		
7	6.51	265	4.4	32	72	3.7	5.0	
8	6.54	250	4.6	34	32	0.7	2.3	
9	6.54	291		12	43	1.5	0.5	
10	6.62	264	5.6	20	50	3.7		1.4
Average				29	46	2.9	2.7	1.4
Ogeechee								
1	5.98	+435	575	90	58		2.5	1.0
2	5.38	301	14.6	220	73		6.0	
3	5.28	296	8.0	220	88		6.1	0.8
4	5.28	268	6.9	300	89		3.0	
5	5.10	256	5.8	250	77		3.3	
6	5.03	268	5.7	465	73	5.4		0.9
7	5.08	251	5.0	275	78	1.0	2.5	0.7
8	5.04	221	4.7	440	85	1.0	3.3	
9	5.04	224	4.4	385	58	4.5	2.5	1.0
10	5.01	224	4.4	465	78	1.0		
Average				311	76	2.6	3.6	0.9
Satilla								
1	7.64	+405	11700	30	38		3.1	
2	7.63	360	10200	35	30		7.0	1.9
3	7.46	367	7800	23	40		1.4	
4	7.19	409	5200	21	37		2.2	
5	7.12	358	4500		38		1.6	
6	6.83	339	3100	17	48	4.7		1.2
7	6.45	321	1200	19	50	0.8	1.8	
8	6.02	399	240		58		3.3	0.9
9	5.93	320	110	81	76	1.0	2.0	1.4
10	5.71	280	40	98	73	2.0		2.3
Average				41	49	2.1	2.8	1.5

samples from the Ogeechee show an approximately exponential decrease going from low to high pH. From Station 10 to Station 1, the Eh also changes to a more oxidizing value. From consideration of pH-Eh relations for iron species in aqueous solutions (Garrels, 1960), it seems reasonable that the iron is floculating out of solution as ferric hydroxide. Mn is also expected to precipitate at higher salinities (higher pH and Eh). This is apparently the case since the lower salinity samples of the Ogeechee are much higher in Mn than those of the higher salinity

Table 3. Elemental Concentration in Suspended Matter.

	Suspended Matter (mg/1)	Fe (%)	Mn ppm	Zn ppm	Cu ppm	Co ppm	Ni ppm	Cr ppm
Altamaha								
1	26.4	4.66	970		401	26	161	376
2	30.9	5.51	950		153	53	257	
3	20.2	6.10	1370		102	44	239	352
4	24.1	5.00	1350	743	135	27	235	141
5	23.8	5.57	1190	593	102	26	187	329
6	19.7	5.18	1290	696	85	37	387	398
7	16.8	5.87	1510	686	108	30	404	221
8	20.5	5.74	1040	1569	124	25		
9	20.2	5.30	1160		183	42		
10	21.9	5.22	1180	787	129			362
Average	22.4	5.91	1200	845	152	34	267	311
Ogeechee								
1	30.0	2.99	258	341	52	30	115	
2	33.9	7.70	299	532	280	29		
3	33.8	6.56	307	316	248	41	137	
4	26.8	6.63	259		323		127	
5	22.1	6.18	151	529	137	34	204	
6	16.4	5.35	177	636	121	43	95	
7	25.0	4.92	174	923	60	24	75	465
8	13.0	3.55		1077	33			
9	13.8	5.41	230	460	92		52	383
10	13.6	5.49	340	448	168	27		249
Average	22.8	5.47	244	584	151	32	115	366
Satilla								
1	19.5	3.94	1300	560	19	16	95	
2	28.3	6.37	1100	707	52		127	
3	55.4	4.41	1300	847	51	16	244	
4	39.9	4.28	1000	670	69	18	167	400
5	53.6	4.58	1100	533	17	25	235	532
6	31.7	3.85	700	533	26	18	235	
7	34.1	4.34	450	135	34	25	106	450
8	52.9	5.46	400	535	40	25	119	500
9	54.7	5.28	420		23	23		
10	65.4	4.73	350	591	89	24	193	
Average	43.5	4.72	812	561	42	21	169	470

samples of the Altamaha and Satilla.

From Figure 5 it appears that rivers in this area deliver iron to the ocean in concentrations equivalent to the approximate average found for the Altamaha and Satilla Rivers instead of the average obtained from the Ogeechee. The high iron content for the Ogeechee is assumed to be associated with the increased runoff mentioned above.

The results of the trace metal analyses of the suspended matter from the rivers are given in Table 3. The blanks in the table represent insufficient material for analyses of all the elements considered. The variations in the chemical compositions of the suspended matter taken at the different stations in a given estuary could not be related to the salinity or the mineralogy, reported elsewhere (Windom et al., 1970). The averages, therefore, are assumed to be the value of the concentration of these metals in suspended matter transported to the ocean from these rivers.

TRACE METAL DISTRIBUTION IN SOUTHEASTERN ESTUARIES

The averages of the trace metal concentrations in the three estuaries (Table 2), with the exception of iron in the Ogeechee, indicate that these rivers are quite similar in dissolved trace metal concentrations. This may be due to chemical reactions, taking place in the estuarine zone, which bring the concentrations of these trace metals into equilibrium with the marine environment. Also, it is likely that the resulting weathering solutions of the drainage basins of these rivers are initially similar with respect to many of the trace metals.

The trace metal content of the suspended matter shows marked differences from river to river. As has been pointed out by Neiheisel and Weaver (1967), the mineralogical composition of the suspended matter is a function of the physiography of the drainage basin of the river. Those rivers having a larger part of their drainage basin in the Piedmont Plateau province have higher concentrations of kaolinite in their suspended loads, whereas rivers having drainage basins located predominantly in the Coastal Plains province contain a greater amount of montmorillonite. With this variation in the mineralogical composition of the suspended matter, it is reasonable to assume that the trace metal composition of the suspended matter will also vary considerably.

Neiheisel and Weaver (1967) as well as Meade (1969) have pointed out the significance of landward transport of sediment derived from offshore areas. It is clear that material originating from these sources could be included in the suspended sediment considered in this study. On the basis of Neiheisel and Weaver's work this material would be rich in montmorillonite and illite. Mineralogical analyses [reported elsewhere (Windom et al., 1970)] of the suspended sediments for the Ogeechee and Altamaha Rivers indicates that these are essentially 100 percent kaolinite. Only the samples collected at Stations 1 and 2 contain any significant amounts of montmorillonite and illite (approximately 30 percent in total). Suspended sediments of the Satilla were a mixture of montmorillonite and kaolinite, consistent with the results of Neiheisel and Weaver (1967) for samples taken further upstream. Here also, only the two most saline stations showed any significant influence from offshore sediment sources. It is therefore assumed that the average

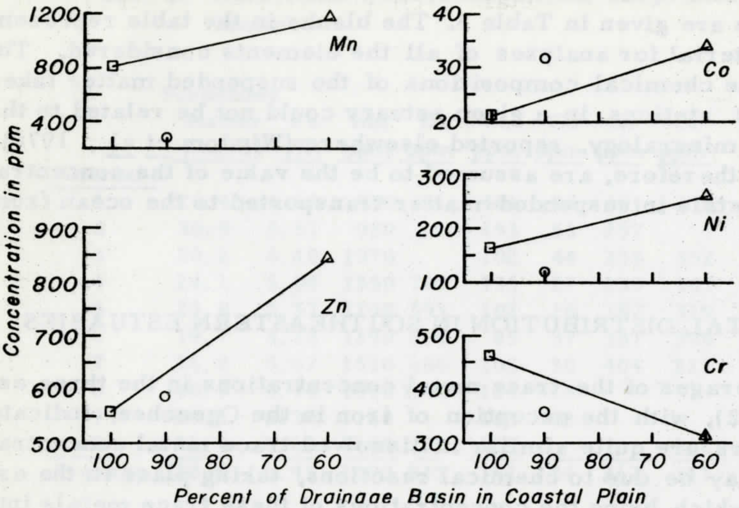

Figure 6. Variation in Trace Metal Concentration of Suspended Sediment in Relation to Drainage Basin Characteristics. Tinage, Circle and Square Represent Altamaha, Ogeechee and Satilla Samples, Respectively.

concentration of trace metals in suspended sediments of the rivers reported here represent what the river is ultimately supplying to the open ocean.

Results shown in Figure 6 suggest that the chemical composition of the suspended matter in Southeastern Rivers is possibly a function of the relative amount of Coastal Plain Province in the drainage basin of the river. The scatter of the values for the Ogeechee River can be explained by dilution of suspended matter with larger concentrations of organic matter washed out of swampy areas during the increased rainfall mentioned earlier. Some of the scatter of the data is also clearly due to the fact that some of the more saline stations include offshore derived sediment.

SUPPLY OF TRACE METALS TO THE ATLANTIC OCEAN

Using the average trace metal concentrations in suspended matter and in solution (Tables 2 and 3) in the Southeastern rivers studied, the supply of trace metals from these rivers to the ocean can be determined. This can then be compared to the accumulation of these metals in the Atlantic Ocean sediments to judge the adequacy of these rivers for supplying trace metals to these deposits.

Table 4 shows the amount of suspended and dissolved trace

Table 4. Supply of Trace Metals from Southeastern Rivers (In 10^{13} μg/1000 Yrs.)

	Mn	Zn	Cu	Co	Ni	Cr
Suspended Load	35	27	4.4	1.1	8.1	12
Dissolved Load	71	4	3.9	< 1.3	1.8	< 1
Total	106	31	8.3	< 2.4	9.9	< 13

Average Post Glacial Rates of Accumulation of Trace Metals in Atlantic Ocean Sediments (In μg/CM^2/1000 Yrs.)*

Mn	Zn	Cu	Co	Ni	Cr
4800	156	156	46	168	103

Area of Atlantic Sediments Which Can be Supplied with Trace Metals by Southeastern Rivers

	Mn	Zn	Cu	Co	Ni	Cr
Area Supplied (Km^2)	22	200	50	<50	60	<130

	Mn	Zn	Cu
Area Supplied / Drainage Area of Source	4.2×10^{-4}	3.8×10^{-3}	9.4×10^{-4}

	Co	Ni	Cr
Area Supplied / Drainage Area of Source	$<9.4\times10^{-4}$	1.1×10^{-3}	$<2.4\times10^{-3}$

*Calculated using average trace metal concentrations on carbonate-free basis for the Atlantic sediments given by Wedepohl (1960) and using a post glacial rate of sediment accumulation on a carbonate-free basis of 1.2 g/Cm^2 · 1000 yr. (Turekian, 1965)

metals which are annually delivered to the ocean from the three rivers studied. These amounts are based on the data given in Tables 1, 2 and 3. Although conclusions are based on one set of sample data for one season, a first order approximation should result. Table 4 also shows the average rate of accumulation of these trace metals in Atlantic Ocean sediments based on the average concentration of these metals in the sediments and the average rate of accumulation of Atlantic Ocean sediments, both on a carbonate-free basis.

By knowing the rate of accumulation of a given trace metal and its rate of supply by the Southeastern rivers, it is then possible to determine the area of Atlantic Ocean sediments that can be produced by these rivers in regard to the given metal. This value is listed for each metal considered in Table 4. It is clear that the area of Atlantic Ocean sediments that can be supplied with trace metals by the three Southeastern Rivers is very small. In fact, it takes about a thousand square kilometers of drainage area to supply one square kilometer of average Atlantic deep sea sediment (Table 4).

CONCLUSIONS

On the basis of the results for the three Southeastern rivers, and because other rivers draining into the North Atlantic are similar in trace metal concentrations (Turekian and Scott, 1967; Kharkar et al.; 1968) and discharges per unit area of drainage basin, it appears that river supply cannot adequately explain the trace metal accumulation of deep sea sediments, particularly for the North Atlantic. This conclusion is based on the assumption that the trace metals are uniformly distributed (the assumption used in Table 4 to calculate average accumulation rates for trace metals in Atlantic sediments). The ratio of the continental area draining into the Atlantic Ocean to the surface area of the Atlantic is about 0.68. In order for rivers draining the continents to adequately supply the necessary trace metals to the Atlantic sediments, the average rate of river transport of these metals per unit area of drainage basin should be about one-third greater than the average rate of accumulation per unit area of sediment.

Turekian and Imbrie (1966) have shown that at least some trace metals such as chromium have higher concentrations in North Atlantic sediments than in those of the South Atlantic. This implies that mechanisms other than river runoff must be more important in the accumulation of some trace metals in North Atlantic sediments. Possible mechanisms for explaining the excess trace metals are vulcanism and wind transport. Turekian (1965) has pointed out the relationship between clay accumulation rate and trace metal accumulation rate. It appears that these metals are most likely associated with detrital minerals rather than authigenic phases. This would tend to favor wind transport since this mechanism has been suggested by many workers as being important to North Atlantic sediments (Griffin et al., 1968; Windom, 1969; and Delaney et al., 1967).

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HEAVY MINERAL ANALYSIS OF THE PARKWOOD FORMATION, CENTRAL ALABAMA

By

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ABSTRACT

The Parkwood Formation of Carboniferous age constitutes part of the Paleozoic sequence exposed in the Valley and Ridge province of north-central Alabama. Analysis of the heavy mineral fraction of sandstones within this formation indicates a source terrane made up primarily of low-rank metamorphic rocks. Evidently, older, undeformed sediments also contributed to the Parkwood detritus. The source area was located probably within the Piedmont complex of eastern Alabama. Consideration of the angularity of the constituent quartz grains together with previous paleocurrent data further supports the idea of a Parkwood provenance situated close by to the east or southeast.

INTRODUCTION

The Parkwood Formation of Carboniferous age crops out in north-central Alabama primarily in three counties---Jefferson, Shelby, and St. Clair (Figure 1). The formation is a repetitious sequence of gray shale, siltstone, and sandstone that has a maximum thickness of more than 1600 feet. The sandstones are made up predominantly of fine-grained quartz with some rock fragments. Ten to 30 per cent of the typical sandstone is composed of silt-sized or finer grains. The average Parkwood sandstone is best classified as an immature orthoquartzite or subgraywacke (using the system of Folk, 1965).

The Parkwood is a prism-shaped body that thins southeast to northwest toward the Warrior Basin and southwest to northeast parallel to depositional strike. The formation conformably overlies Mississippian shales and is overlain conformably (in most places) by Pottsville clastics of Early Pennsylvanian age. On the basis of fossil data, the stratigraphic position of the Parkwood has been defined as uppermost Mississippian-lowest Pennsylvanian (Butts, 1926; Culbertson, 1964; Whisonant, 1965).

The Parkwood has received detailed attention primarily in the studies of Butts (1910; 1926), Culbertson (1963; 1964), and Whisonant

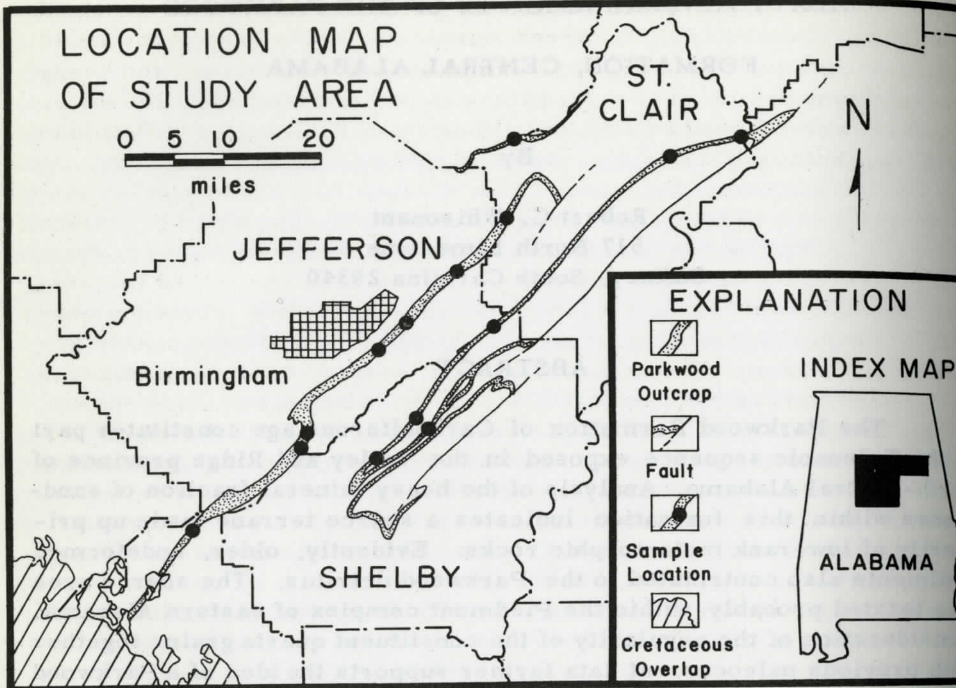

Figure 1. Location map of the study area showing exposures where samples were collected (Parkwood outcrop pattern taken from Butts, 1926).

(1965). The present report presents data concerning the heavy mineral fraction from sandstones within this formation. In addition, inferences from these data are made as to the nature of the Parkwood source area and its probable location.

Acknowledgement

This paper is based upon a M. S. thesis submitted to the Florida State University. I wish to thank W. F. Tanner, Jr., who suggested the problem and contributed many helpful suggestions during the course of the work.

HEAVY MINERAL ANALYSIS

Procedure

Fresh typical Parkwood sandstone is medium gray and extremely well indurated. Weathered samples, however, commonly are friable, thus permitting disaggregation and sedimentologic analysis by standard techniques. Twenty-four weathered samples were obtained from the 14 localities shown in Figure 1. The samples were crushed and the heavy minerals removed through separation with tetrabromethane. The heavy minerals were identified using the data from Krumbein and Pettijohn (1938) and Milner (1962).

Results

The heavy mineral data for all samples are presented in Table 1 as the combined grain counts and the corresponding frequency percentage for each species present. Each type has also been ranked according to its order of abundance. Finally, the frequency percentages of all heavy mineral species exclusive of the opaque grains are shown.

Comparison of the order of abundance to expected chemical stabilities (see, e. g., Pettijohn, 1957, p. 506) indicates that weathering probably has not significantly altered the original heavy mineral suite. For example, garnet, monazite, and rutile, all very stable minerals, are not as abundant as hornblende, a less persistent mineral. No significant differences in grain size are evident among the various heavy mineral types present. This indicates that the distribution differences shown by the grain count frequencies represent variations in percentages by weight as well.

The opaque minerals are composed predominantly of dull white subrounded grains identified by X-ray analysis as leucoxene (consisting of finely crystalline rutile and possibly some brookite and anatase). Hematite, limonite, and well-rounded magnetite and ilmenite grains also make up part of the opaque assemblage. Irregular aggregates of pyrite are rare. Rock fragments in the concentrate are derived mainly from schist and phyllite; sparse fragments of slate occur also. Some of the fragments contain plagioclase.

Zircon occurs most typically as well-rounded equant grains; however, an elongate variety is also present. Color varieties of rounded to well-rounded grains of tourmaline include green, green-brown, brown, pink, blue, and gray. The green type is the most abundant. A very dark green, essentially opaque, variety of hornblende is the more abundant of two kinds present. Less plentiful is a brown species, possibly oxy-hornblende. The hornblende, staurolite, rutile, garnet (pale pink), and monazite all occur as rounded to well-rounded grains.

The light fractions of the Parkwood sands consist primarily of quartz. No orthoclase is present and only a few grains of plagioclase occur. The quartz grains typically are moderately spherical and subangular to angular; however, the coarse sizes (0.5 to 1.5 phi) commonly are rounded to subrounded.

Table 1. Total Heavy Mineral Percentages of Parkwood Sandstones.

Mineral	Total Grains Counted	Frequency Percentage	Rank by Order of Abundance	Frequency Percentage Omitting Opaque Grains
Biotite	17	0.2	9	0.5
Chlorite	33	0.3	8	1.0
Garnet	6	0.1	10	0.2
Hornblende	345	3.4	5	10.5
Monazite	5	0.1	10	0.2
Muscovite	925	9.2	3	28.1
Opaques	6793	67.4	1	-
Ortho-pyroxene	13	0.1	10	0.4
Rutile	85	0.8	7	2.6
Staurolite	98	1.0	6	3.0
Tourmaline	356	3.5	4	10.8
Zircon	1403	13.9	2	42.7
Total	10079	100.0		100.0

Interpretation

The heavy mineral assemblage found in the Parkwood sandstones is indicative of two major source rock types, reworked sediments and low-rank metamorphics (Pettijohn, 1957). The high degree of rounding of the more stable minerals (including zircon, magnetite, ilmenite, tourmaline, monazite, rutile, garnet, and staurolite) suggests that they were inherited from pre-existing sediments. The common occurrence of slaty, phyllitic, and schistose rock fragments associated with detrital biotite, muscovite, and chlorite plus leucoxene is indicative of low-rank metamorphic source rocks. A general absence of feldspars is also expected in sandstones having such an origin. The presence of brown "basaltic" or oxy-hornblende indicates that unmetamorphosed basic igneous flows or plutons may have made some small detrital contribution to the Parkwood clastics (Krumbein and Pettijohn, 1938).

Several previous studies of the Carboniferous clastic wedge (i. e., Floyd-Parkwood-Pottsville) of north-central Alabama have suggested a southeastern source terrane for these sediments (King, 1950; Cooper, 1964). Other authors (Ehrlich, 1965; Thomas, 1965) have argued that a Ouachita system provenance to the southwest was dominant over any Appalachian source.

I believe that the Parkwood source area was located in the Piedmont complex east of the present Parkwood outcrop belts. This region contains a varied group of metamorphic and igneous rocks (Adams, 1926; Baker, 1957; Deininger and others, 1964) that could have supplied the Parkwood heavy minerals. Slates, phyllites, and schists are particularly abundant in the Piedmont. Furthermore, basic igneous masses (both intrusive and extrusive), such as might have contributed brown hornblende, are present.

The Parkwood clastics reflect the increasing pace of a developing orogeny that finally in Pennsylvanian time produced what probably were considerable highland source areas to the east. During Parkwood deposition, the distributive provenance in the Piedmont apparently was not as strongly deformed as the present crystalline complex. Rather, the source terrane was made up in large part of pre-Parkwood sediments deposited after the last regional metamorphic event. In Parkwood time these pre-existing sediments were undergoing low to moderate deformation in the early to middle stages of the final orogenic episode. The pre-Parkwood strata contained relict rounded detrital grains of staurolite, garnet, rutile, monazite, and other minerals from older, medium- to high-rank metamorphic and igneous rocks of the Piedmont hinterland, but were themselves only lightly metamorphosed. A mildly deformed provenance is further implied by the lack in the Parkwood of any medium- or high-rank metamorphic index minerals displaying no evidence of sedimentary recycling.

The brief examination of the light fraction indicates a Parkwood source terrane situated nearby. The typically angular to subangular quartz grains evidently reflect short-term transport. If the Parkwood sediments were derived from areas within the Piedmont, presently located about 20 miles from the study area, then very little rounding of the quartz would be expected.

One other important line of evidence points toward a southeastern source area. Numerous cross-bedding studies involving the Carboniferous strata of northern Alabama have demonstrated westward, southwestward, or southward current directions during deposition of these sediments (see discussion in Whisonant, 1967).

SUMMARY

The data presented here indicate a Parkwood source area that was most likely a complex of metamorphic rocks in a low to moderate stage of deformation and undeformed sediments. The angularity of the quartz grains implies a source terrane located near the present outcrop area. Previous work concerning paleocurrents from the Parkwood and Pottsville clastics suggests a provenance situated to the east or southeast. Consideration of all these observations points toward a Parkwood source area located within the Piedmont complex of eastern Alabama.

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HYDROLOGIC EFFECTS OF QUATERNARY SEDIMENTS ABOVE THE MARINE TERRACES IN THE GEORGIA COASTAL PLAIN[1/]

By

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ABSTRACT

Quaternary and Recent eolian and fluvial sediments (sands) have a characteristic distribution pattern on watersheds in the Coastal Plain of Georgia above 320 feet MSL or the highest unnamed marine terraces. The streams lie on the western side of south-draining valleys, and the maximum eolian and fluvial sediment thickness (sand dunes) is attained east of the stream and on the west-facing valley flank. The minimum sediment thickness was observed on the east-facing west side of the watersheds. Also, watersheds with a west-facing aspect act as a catchment basin and, hence, have deeper Quaternary and Recent sediment accumulations. These sediments form a highly permeable veneer over the older marine formations. They vary in thickness throughout the watershed with the maximum being 20 to 25 feet. This veneer acts as a shallow phreatic aquifer throughout the basins, making groundwater available to deep recharge, return flow to streams, and evapotranspiration. A higher concentration of sinkholes has been noted in the elongated sand dune area east of the present-day major streams where the maximum accumulation of Quaternary and Recent sands was noted. The eolian and fluvial sediment distribution was controlled by the source area, pre-Quaternary stream network, and the prevailing winds. This dune distribution pattern seems more pronounced in the outcrop area of the Miocene age - Hawthorn Formation. These sands have a major effect on the stream runoff, pond and pit site location, drainage systems, soil development, watershed infiltration rates, and recent and

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1/ Contribution from the Southern Branch, Soil and Water Conservation Research Division, Agricultural Research Service, USDA, in cooperation with the University of Georgia College of Agriculture Experiment Stations and Middle South Georgia Soil Conservation District.

paleo-stream channel location. Hence, before watershed hydrologic performance can be understood and predicted and watershed protection and development programs applied, it is necessary to understand this shallow phreatic aquifer and its distribution.

INTRODUCTION

Before one can understand and predict the hydrologic performance of watersheds, it is necessary to understand the geology, soils, and landforms. This is especially important in the southern Coastal Plain where surface materials, in many cases, have high infiltration rates and are underlain by materials of lower permeability at shallow depths (3 to 20 feet). Here, yield of direct surface runoff is low, but yield of delayed flow (shallow phreatic interflow) is high.

An explanation for the distribution of loose unconsolidated Quaternary and Recent sediments above 320 feet mean-sea-level (MSL) that transmit shallow subsurface flow within watersheds in the Coastal Plain is advanced. These sediments have a characteristic depositional pattern which undoubtedly acts as a major control on phreatic groundwater movement and surface runoff.

DISCUSSION

Sea transgression and retreat occurred many times during the deposition of the Coastal Plain sediments. Hence, the sediments were alternately eroded and deposited. LeGrand (1962) stated that after deposition of the Cretaceous sediments, the seas withdrew and a gradual tilting seaward of the Coastal Plain occurred. During Tertiary times, seas again transgressed the area; and sediments, chiefly limestones, thickening seaward were deposited (LeGrand, 1962). These Tertiary sediments have since undergone mechanical and solution erosion. The streams flow down regional slopes in courses superposed from deposits of their own former aggradational bed load (White, 1966). The major paleo and recent stream flow in the Coastal Plain of Georgia also, in general, parallels the dip of the Tertiary and Quaternary sediments.

W. A. White (1966) reported a sequence of seaward cape growth of the Carolina Capes. This growth began at the Fall Zone and moved seaward by an emergence of off-cape shoals. New capes were formed from relic capes during sea-level rises. Hence, the capes formed major asymmetric drainage divides, and the drainage was confined between the divides. White also found that the main streams lie immediately northeast of the lines of capes. This deflected-trunk drainage pattern is also shown in Georgia and Florida in the Apalachee Bay to Pascagoula, Mississippi area. Johnson and DuBar (1964) reported elongated northeasterly-oriented sand dunes in Bladen County, North

Carolina. They attributed this dune pattern to the ancient flood plain surface being swept by southwesterly winds during or sometime after the period when the Carolina bays were formed. They also sited several other areas where the sand dunes showed a characteristic orientation caused by southwesterly winds. The effect of this dune pattern on drainage, infiltration, stream flow, and water quality of watersheds between the drainage divides is of prime interest to watershed engineers.

River valleys on the Atlantic Coastal Plain are bounded by ascending terraces which are not separate fluvial terraces and are not necessarily indicative of unique individual base levels (Colquhoun, 1966). The area is characterized by constructional and destructional landforms separated by scarps of continental and marine origin. These terraces vary in elevation from 8 feet MSL (Silver Bluff) to 250 feet (Hazlehurst) and to the highest reported 320 feet (unnamed) (Doering, 1960 and Colquhoun, 1966). The lowest four terraces (8, 17, 40, and 180 feet MSL) are of Pleistocene age, and the other terraces are pre-Pleistocene (Colquhoun, 1966). Tanner (1968) reported as a corollary to mid-Tertiary ice development in Antarctica that sea level began to drop about mid-Tertiary time in the southeastern United States. He stated that this was certainly no later than Miocene. He found that terraces in Florida above 30.5 feet were pre-Pleistocene and that sea-level oscillation began when the Northern Hemisphere ice sheets assumed continental proportion. This oscillation was on a steady falling level with no recovery being equal to any previous high (Tanner, 1965).

B. G. Thom (1970) postulated that Carolina bays (Horry County and Marion County, South Carolina) developed from shallow lakes during mid-to-late Wisconsin. Thom attributed the stabilized parabolic dunes in river valleys to southwest and west-southwest winds. He also made note of parabolic dunes on the Altamaha River in Georgia, which he related to one period of strong dune construction during late Quaternary time. This study is concerned with watersheds whose elevations are, in general, above 320 feet MSL, while Thom's studies were below 120 feet MSL. Wright (1961) attributed intensive frost and wind action to the Pleistocene periglacial environment in Europe. He stated "The occurrence of extensive sand dunes and loess deposits may be related to the distribution of glaciofluvial plains, strong winds, and the absence of forest cover."

Quaternary and Recent sediments lying at higher elevations than the marine terraces, which form shallow phreatic aquifers over a large area of the Coastal Plain of Georgia, have undoubtedly undergone eolian and fluvial erosional and depositional environments rather than marine. Watersheds in the Georgia Coastal Plain at lower elevation have undergone, to varying degrees, eolian and fluvial erosion and deposition since the marine terrace deposition. The author believes that the amount of this eolian and fluvial action becomes less at lower MSL elevations or as the sediment age decreases. Physiographic divisions of South Georgia are shown in Figure 1. Areas that lie above 320 feet

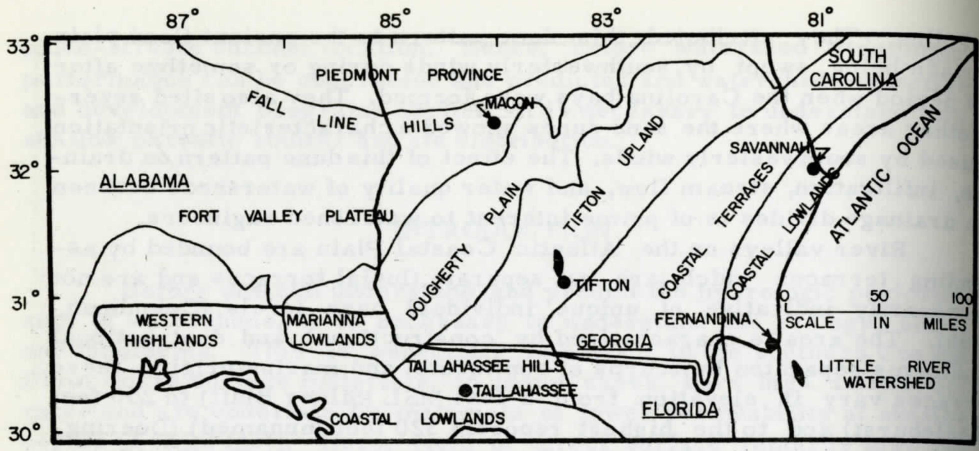

Figure 1. Physiographic divisions of South Georgia and North Florida. (Stringfield, 1966)

(MSL) are found in the Tifton Upland, Dougherty Plain, and Fort Valley Plateau. Within these subprovinces, elevations range from 100 feet to 600 feet (MSL). Therefore, only a portion of the area lies above 320 feet and exhibits only eolian and fluvial depositional and erosional characteristics. Whereas, sediments occurring below 320 feet (MSL) will show characteristically marine depositional patterns and, in some instances, a surficial cover of eolian and fluvial sediments.

Stratigraphically, the Tifton Upland, in general, lies in the outcrop area of the Miocene series, Hawthorn Formation (Figure 2). The Dougherty Plain is located primarily on sediments of Oligocene and Upper Eocene age, and the Fort Valley Plateau is in the outcrop area of the Upper Eocene, Barnwell Formation.

A seismic study was made with a portable refraction seismograph of one outcrop area of these shallow sediments. This area lies in the Little River experimental watershed, Tifton, Georgia (Figure 1). The parent geologic material is the Hawthorn Formation overlain by Quaternary sands. The elevation varies from 370 feet to approximately 400 feet (Figure 3). Several outcrop areas of these shallow sediments are located in this watershed. In addition to the mapped sand outcrop area shown on Figure 3, the author has noted similar areas on other streams in this watershed. Also, similar deposits have been observed on adjoining and other watersheds in the Coastal Plain of Georgia. These sand deposits are found under similar geologic and topographic conditions.

Three traverses were run across one outcrop area (Figure 3). The cross-section at Site One was divided into three arms: A, B, and C (Figure 4). Figure 5 shows Traverse Two and Three. All the Quaternary and Recent sediments lie above 320 feet, or the highest reported marine terrace, with the exception of Cross-Section 1-A. Hence,

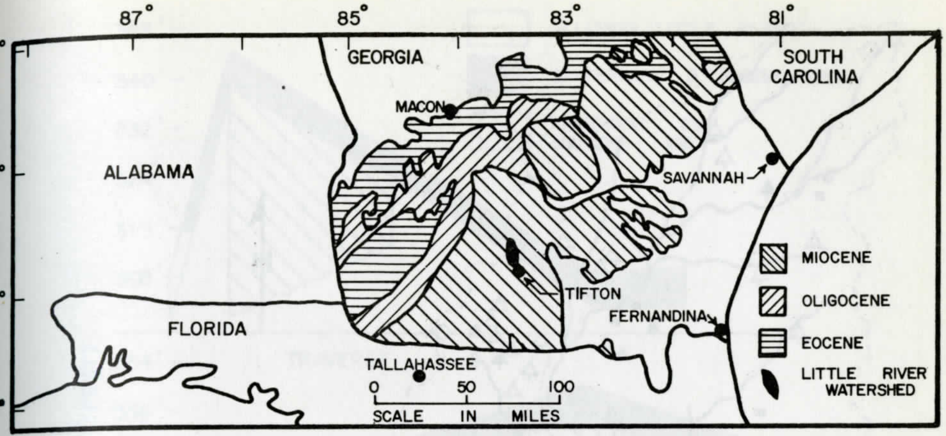

Figure 2. Outcrop map of South Georgia. (Stringfield, 1966).

these sediments are undoubtedly eolian and fluvial.

Carver (1967) and Kelley (1967) have also noted that streams draining south and southeast have eolian and fluvial sand concentrations on the east and northeast side of channels. Examples of other rivers showing dunes developing on the eastern side of the major channels are the Alapaha and Flint Rivers. The Kershaw, Troup, and other soils with high infiltration rates developed on these eolian and fluvial sands and have a major effect on the watershed hydrology. The palmetto, scrub oak, pine, and in some cases farm crop cover also affect the hydrology. Figure 6 shows one of the sand outcrop areas on the Little River watershed. The water is perched on the contact of the Hawthorn Formation, which forms the base of this sand pit. This is in the general area where the above mentioned cross-sections were run. It would be expected that pits dug into or adjoining these sand dunes would all act as a collector for this groundwater. This perched water is also available to return to the streams as base flow and evapotranspiration; hence, it must be considered when locating ponds or pits. The writer has noted that the Quaternary sediments are very thin or, in many cases, absent on the east-facing west side of watersheds. As a rule, the sands begin east of the present stream and reach a maximum thickness in the buried pre-Quaternary stream network which, in general, lies to the east of the present-day network. They then continue up the west-facing east slope of the watershed. The deposition of the Quaternary sediments on the eastern side of the major streams has presumably caused the westward migration of the drainage net from approximately 100 to 300 feet, causing the main drainage channel on watersheds in the Tifton Upland and Dougherty Plain to be located on the west side of the valley alluvium. The valley alluvium is incised into the parent material and is, in general, on the west side of the watershed. This westward migration may also be partially due to the Coriolis forces

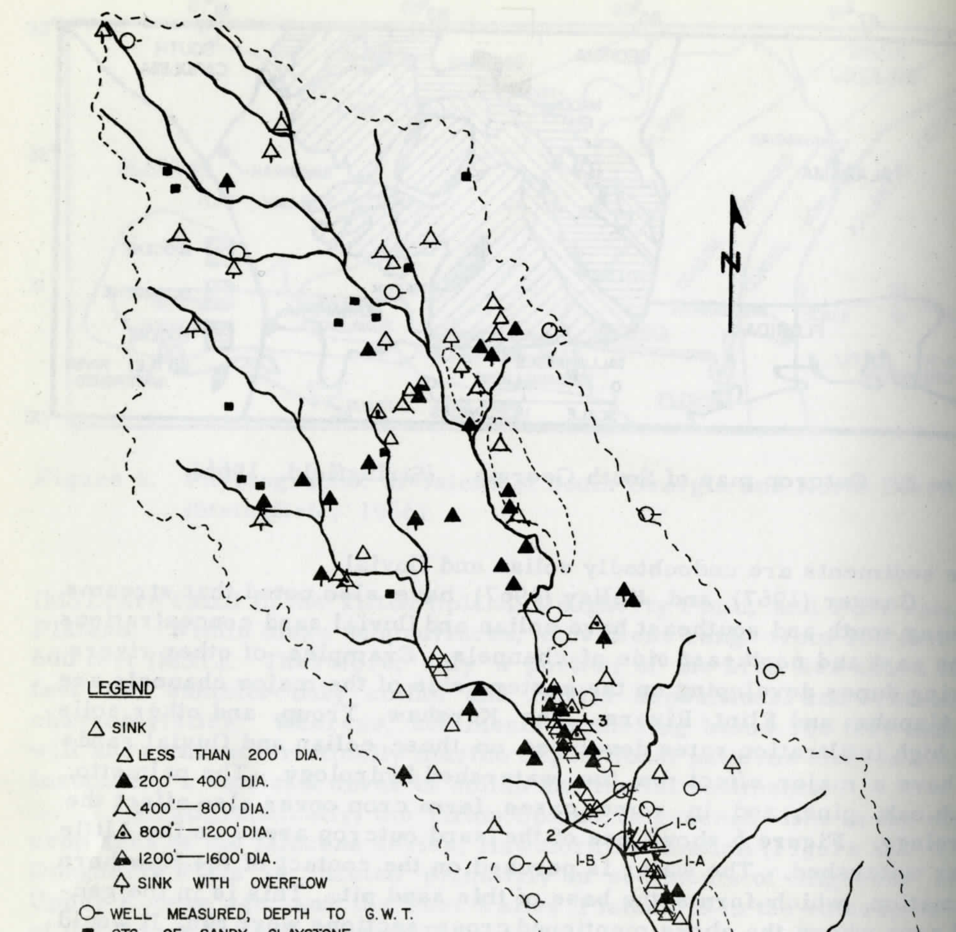

Figure 3. Geological reconnaissance map of Little River Watershed, Tifton, Georgia. Map prepared by R. E. Carver under contract and with the Southeast Watershed Research Center.

(Wright, 1961). Work to date on the Little River and other watersheds in the immediate area indicates that the pre-Quaternary drainage

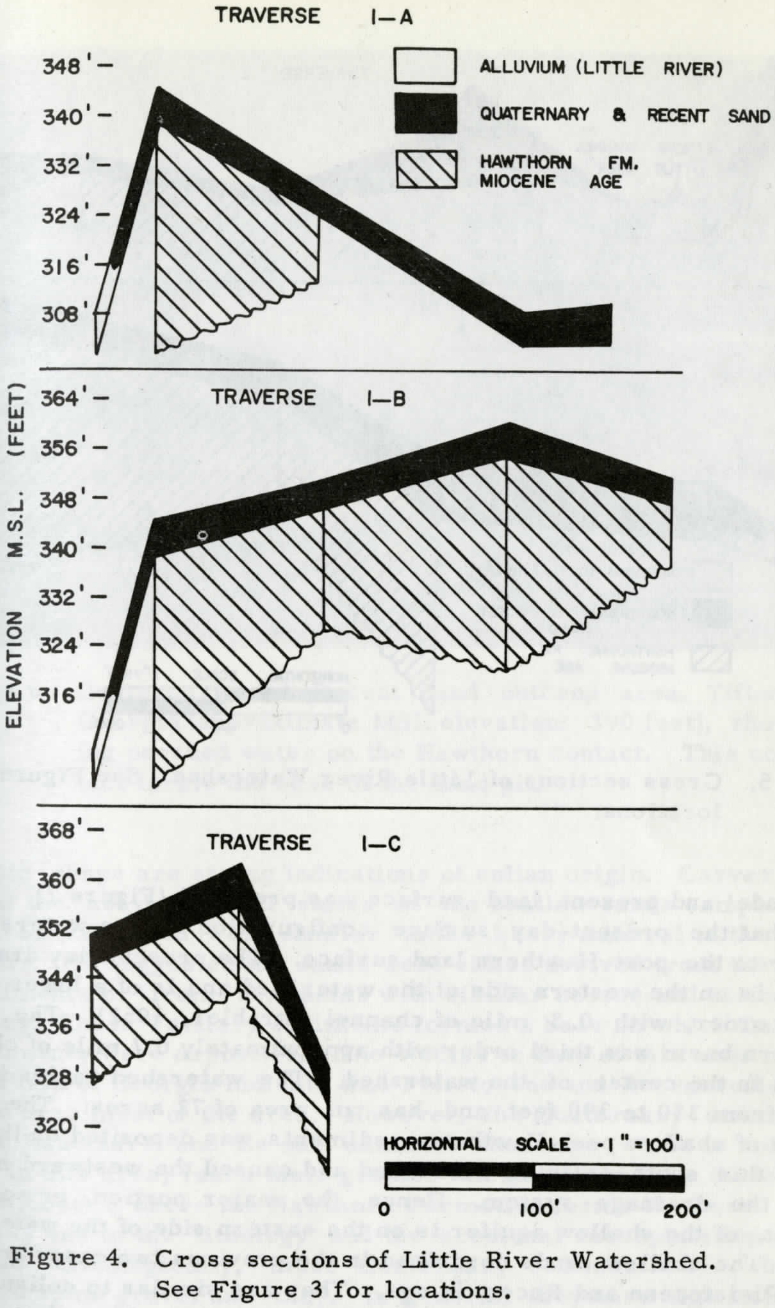

Figure 4. Cross sections of Little River Watershed. See Figure 3 for locations.

networks were of a higher order (Strahler, 1952) than the present system. These old stream networks, when filled with eolian and fluvial sands, act as collectors and conduit for the shallow phreatic groundwater.

A second area, Walker Pond watershed, 5 miles south of Tifton and Little River watershed was core drilled; and a map of the Hawthorn

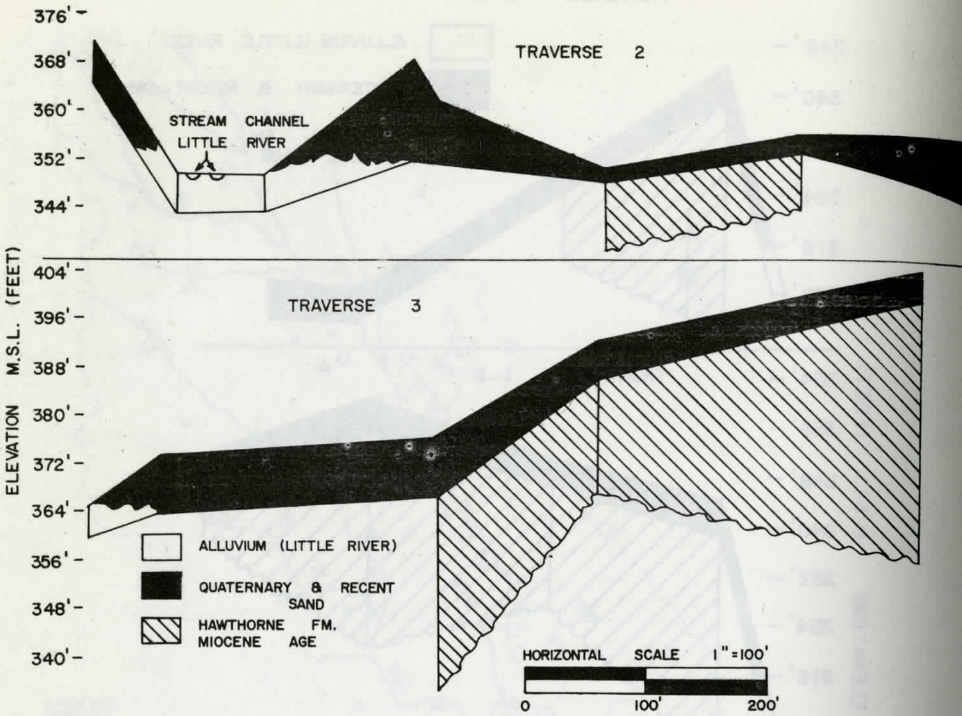

Figure 5. Cross sections of Little River Watershed. See Figure 3 for locations.

(aquiclude) and present land surface was prepared (Figure 7). It was found that the present-day surface configuration for the watershed is similar to the post-Hawthorn land surface. The present-day drainage system is on the western side of the watershed and is of a lower order, second order, with 0.3 mile of channel (Strahler, 1952). The post-Hawthorn basin was third order with approximately 0.7 mile of channel located in the center of the watershed. The watershed varies in elevation from 330 to 390 feet and has an area of 72 acres. The major portion of shallow post-Hawthorn sediments was deposited on the east side of this south-draining watershed and caused the westward migration of the drainage system. Hence, the major portion, or some 85 percent, of the shallow aquifer is on the eastern side of the watershed.

The shallow sands described in the previous two cases are probably Pleistocene and Recent in age. They are similar to eolian sands found at Albany, Georgia, by Kelley (1967) and at Hawkinsville, Georgia, by Carver (1967). The heavy mineral suite of the Albany sands is rich in hornblende while those found on the Little River and Walker Pond watersheds lack appreciable quantities of hornblende.

The sand's surficial character, location, and distribution within the watershed; the elongated shape of the major outcrop areas; the location of major outcrops east of the major stream network; and the

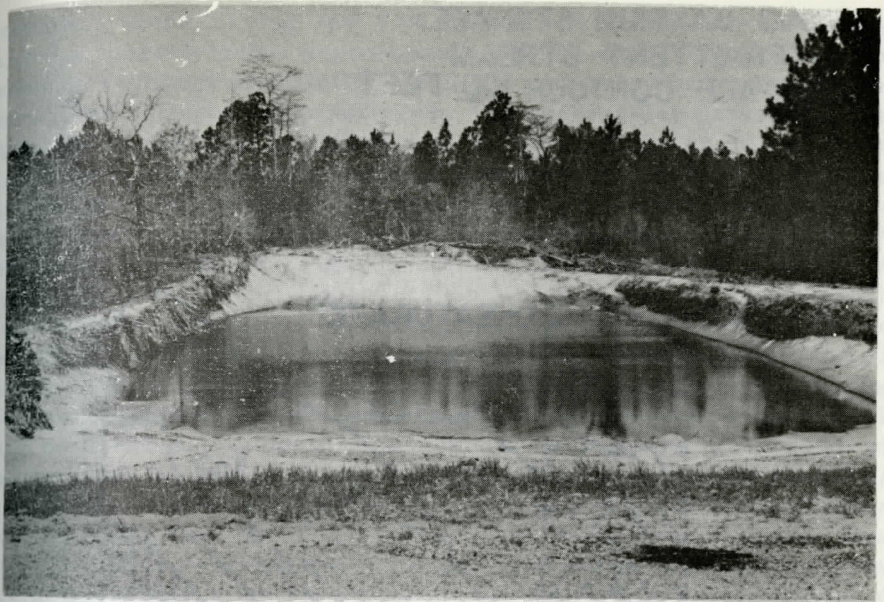

Figure 6. Quaternary and Recent Sand outcrop area, Tifton, Georgia (approximate MSL elevation: 390 feet), showing perched water on the Hawthorn contact. This contact forms the base of the sand pit.

sand-grain shape are strong indications of eolian origin. Carver also found that the heavy mineral suites of the shallow sands sampled on Little River watershed were similar to the heavy mineral of the Miocene sands. He suggested the sands were either derived from the Miocene sediments or from sediments with similar source and history of weathering. These Tertiary sediments formed a base on which Quaternary sediments were deposited. The studies to date of this area of the Coastal Plain of Georgia indicate that Pleistocene and Recent sediments are found over most of the area. However, the Quaternary sediments above the Hazlehurst and the one unnamed shoreline (which is not discernible in this area) reach their greater thickness and have the largest areal distribution where the Hawthorn Formation forms the base. This is probably due to the lithology and the erosional susceptability of the formation. Lithologically, these Quaternary sediments are chiefly sands with some gravel and clay. In general, they have high infiltration and transmissibility rates.

CONCLUSIONS

It is hypothesized that two major factors that control the distribution of the Pleistocene and Recent eolian and fluvial sediments on

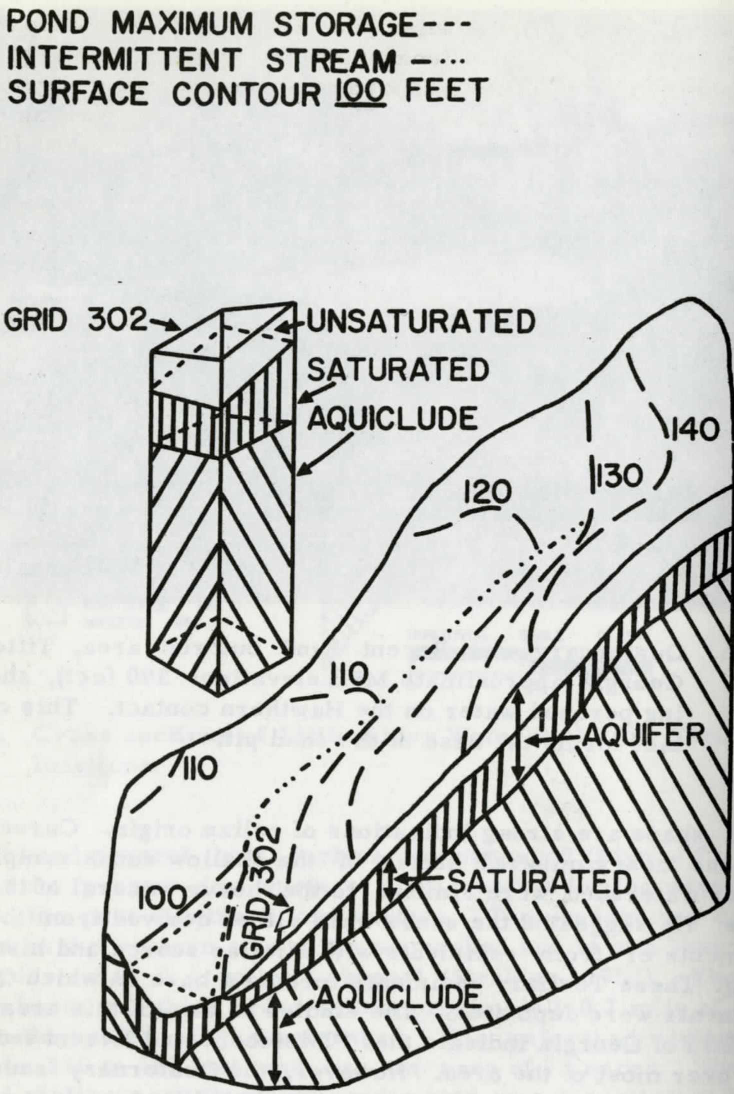

Figure 7. Walker Pond Watershed, 5 miles south of Tifton and Little River Watershed.

headwater watersheds above 320 feet MSL are: 1. pre-Quaternary drainage network and 2. east, southeast or south prevailing winds. The drainage network parallels the dip of the older sediments which is south to southeast. The regional dip has been in this general direction since post-Cretaceous time. Therefore, present-day major watershed axes and major stream orientation in the Coastal Plain of Georgia above the highest marine terrace should be similar to pre-Quaternary time, differing only where modified by eolian and fluvial deposition.

Prevailing winds during the Pleistocene and Recent times apparently caused a characteristic depositional pattern which depended to some extent on sediment availability within the watershed and on vegetational and watershed topographic features. The present-day prevailing annual wind is southeast at a mean speed of 9 mph and between 60 and 70 mph fastest mile of wind (U. S. Dept. of Commerce, 1968). This present-day wind pattern would also be conducive to observed Quaternary and Recent sediment distribution and this dune formation. Hamilton (1968) relates the present-day rigorous Northern Hemisphere winter to the Arctic Ocean ice cover. It would then, in turn, seem reasonable that these rigorous conditions existed during the Pleistocene glacial periods only at lower latitudes. It is also reasonable to suppose that the prevailing wind patterns of our present Northern Hemisphere (U. S. Dept. of Commerce, 1968) in the area south of the Arctic Ocean would also have occurred during the glacial periods. Projecting this present wind pattern from the known glaciated Central United States, the annual prevailing wind direction above the marine terraces in the Coastal Plain of Georgia would have been, in general, east, southeast, or south. These strong winds were undoubtedly capable of moving sand-size materials in traction and smaller materials in suspension with ease. Hence, deposition of the materials in the present-day outcrop patterns would be possible. The winds and streams would also tend to separate the materials into size fractions. It is postulated that the immediate source of the sand was in or near the stream channels and in the upland where weathering of the parent Miocene sediments occurred. Under today's climatic conditions, streambeds in the Tifton Uplands are dry during the late-summer months, and the sandy-bed materials and the weathered upland parent materials are vulnerable to movement by strong winds. Wind-blown-sediment movement as described above has been noted by the author on both of the study watersheds. Pleistocene winds were probably responsible for the major portion of the sediment movement, with present-day winds contributing only minor amounts. Therefore, watersheds located in the Tifton Upland, Dougherty Plain, and Fort Valley Plateau having Quaternary sedimentary cover above 320 feet may be expected to have shallow phreatic aquifers with predictable distribution within the watershed.

Hydrologically, on a unit area basis it would be expected that more direct surface runoff comes from the west side of a watershed; and conversely, more interflow and less direct surface runoff comes from the east side of the watershed. These old stream networks, which act as collectors for the shallow subsurface flow, can, when tapped, provide a source of recharge water for ponds and pits. These old networks also explain some of the agricultural drainage problems in certain areas. Small subwatersheds located along the north-south drainage pattern that drain to the west would be expected to have a deeper-than-average Quaternary aquifer. Due to this aspect, the watershed would have a tendency to act as a catchment basin for the eolian sediments. Hence, these watersheds would have different hydrologic performances than watersheds oriented in other directions.

The Quaternary eolian sediments and their distribution also seem to be related to sinkhole development. An increased frequency of sinkholes has been noted by the author and R. E. Carver (1969 Personal communication) in areas where the eolian and fluvial sediments are concentrated. This is particularly true in the areas of the pre-Quaternary stream network. The Quaternary sand outcrop area in the Little River watershed is 5.1 percent of the 145 square mile area (Figure 3). There are 97 sinkholes in the watershed, and 40.2 percent of these are in the eolian sand outcrop area. The total sinkhole surface area in the watershed is 2.24 square miles, and 1.17 square miles of the surface area are in this major sand outcrop area. Hence, 52.8 percent of the sinkhole surface area is in the eolian sand outcrop area, which is only 5.1 percent of the total watershed. This increased sinkhole concentration may be due to high surface infiltration rates which make larger amounts of precipitation available for groundwater movement and solution development. This is another indication of the possible effect that the Pleistocene and Recent sediments have on Coastal Plain hydrology.

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